HISTORY OF THE LATHE TO 1850

Robert S. Woodbury

HISTORY OF THE LATHE TO 1850

A Study in the Growth of a Technical Element of an Industrial Economy

For

ABBOTT PAYSON USHER

who first showed

the historical interdependence

of technology

and the economy

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TABLE OF CONTENTS

PREFACE

Since the days of Marx, Sombart and Veblen the economic and social theorists and historians have been aware of the powerful influence of technology in our industrial society. But only a few, such as Usher, have gone beyond mentioning the steam engine and Watt, textile machinery and Arkwright, steel and Bessemer. Yet we are now at the point where even the political and diplomatic historians will have to have some understanding of technological innovation, and it becomes more and more evident that any meaningful attempt to account for an industrial society must include a detailed picture of its technology.

It is not enough to consider only the social and economic repercussions of technology, for these find their technical origins in times and men often remote from the great events to which they contribute such important elements. It is essential to look carefully at the actual technical development itself—the "hardware." And if one does, it becomes increasingly evident that while the engineer and technician are of course influenced by the society and the economy in which they work and live, there is a certain inner compulsion of technological development which is quite independent of social and economic forces. One must recognize that if a certain problem cannot be solved in terms of the technology of the times no amount of economic and social pressures will bring about a solution. Conversely, technological innovation may come about quite independent of any demand from society, yet quickly have enormous economic and social influence. Equally the historian of technology must keep clearly in mind that the most brilliant technological development can have significance only in a suitable economic and social situa-

tion. But for the moment he can only continually beg the economic and social historians at least to look at the picture he has drawn of the technological development itself, in which he has only suggested the broader implications.

The present monograph is then intended only as a study in one *technical* element of an industrial society. It is further limited, not only by the almost virgin state of scholarship in the history of technology but by the lack of scholarly studies on the history of machine tools —the technical element without which the developments in steel, complex machinery, and power would not have been possible. It is the fourth in a series of monographs aimed at providing a sound basis for writing a two-volume *History of Metal-Cutting Machine Tools* expected to appear about 1963, in which it will be possible to relate the development of each machine tool more directly to the others, to problems of mass production, and to the economy and society in which they appear and play their part. The undeveloped state of the history of technology and the pioneer character of these monographs make inevitable gaps in the evidence, of which the author is only too painfully aware. But the detailed map must be left to later scholars, when so much virgin territory cries out merely to be explored.

When making the preliminary analysis and survey for the entire series, it at first seemed likely that no monograph on the history of the lathe would be required. The studies on the lathe in antiquity by A. Rieth[1] and the detailed doctoral dissertation of Karl

1. Adolf Rieth, "Zur Technik antiker und prähistorischer Kunst: Das Holzdrechseln," in *Jahrbuch für Prähistorische und Ethnographische Kunst*, Vol. 13/14, 1939-40, pp. 85-107; "Drechseltechnik und Drehbank in antiker Zeit," in *Forschungen und Fortschritte*, Vol. 17, 1941, pp. 369-371; "Die Entwickung der Drechseltecknik," in *Jahrbuch des Deutschen Archäologischen Institutes mit dem Beiblatt Archäologischen Anzeiger*, Vol. 55, 1940, pp. 615-634. See also, Adolf Rieth and Karl Langenbacher, *Die Entwicklung der Drehbank*, Stuttgart, n.d. (ca. 1941).

Wittmann[2] appeared to provide most of the monographic work needed to write an adequate account of the development of the lathe. Further study of their results, however, made it clear that although both authors provide a wealth of data, their analyses and their interpretations need substantial revision. Most of Rieth's conclusions have had to be rejected, even if his facts are sound. Wittmann's treatment of the history of the lathe to 1850 is not based upon the sources. After that period he is very full and detailed, but confines himself almost entirely to the technical development and even there writes with little analysis or interpretation. However, for the purposes of this series of studies on the history of machine tools, Wittmann's account of the later development of the lathe is sufficiently satisfactory for me to end my own monograph at 1850.

Except for the English development as described by Smiles and Nasmyth, accounts of the history of the lathe are largely the work of German scholars, and their books are out of print. It therefore seemed advisable to provide in English a fresh analysis of the development of the lathe and some indication of the part it played in the early growth of our industrial society.

Special thanks are due to my colleague Professor Cyril Stanley Smith, who kindly read the manuscript in its entirety, offered valuable suggestions, and allowed me to examine the text and illustrations for the forthcoming Hawthorne-Smith edition and translation of Theophilus. Professor Richard S. Hartenberg of Northwestern University also read the complete manuscript and raised some important points about the possibility of turning stone column drums in antiquity. My colleague Professor Harald A. T. O. Reiche helped with sev-

2. Karl Wittmann, *Die Entwicklung der Drehbank*, Berlin, 1941. Complete English translations of Wittmann and Rieth are available for loan to interested students of the lathe.

eral troublesome points of classical scholarship, and Dr. Torsten K. W. Althin, Director, Tekniska Museet, Stockholm, generously supplied much material on Polhem. Dr. Maurice Daumas of the Conservatoire National des Arts et Métiers supplied information on the lathe of Vaucanson. Professor Lynn White, Jr., of the University of California, Los Angeles, drew my attention to an important drawing of a lathe in the Louvre. Mr. Leroy Thwing kindly allowed me to use his fine copy of the first edition of Plumier, and Mr. Warren Ogden, Jr., loaned me a number of items from his rich collection on the ornamental turning lathe. I owe a special debt to my research assistants Sarah Holschneider, Heiner Sussebach, and Miriam Dergalis.

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Cambridge, Massachusetts
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INTRODUCTION

The lathe is probably the oldest of the developed machine tools; with the bow drill it was the only complex tool known to antiquity. In fact until the end of the 18th century, these two tools were technically by far the most important available to the mechanic.

Although there is some evidence for quite early use of the lathe to work metals,[3] it was so used only on the non-ferrous metals, and one may clearly say that until the 18th century the lathe was primarily a woodworking machine. In this early period the lathe produced articles for everyday use, but it had an equally important function as a means of decoration of its products.

Much loose speculation has led to confusion in attempting to determine the origin of the lathe. Feldhaus[4] posits a "universal machine" and then tries to convince us that he has found evidence to justify it. Others, naive in ethnology, have examined the lathes used by a number of primitive people in modern times and assumed that we can establish the early form of the lathe from such studies. Still others have tried to show how the drill-bow or the potter's wheel would require only "slight" mechanical changes to make them into an elementary lathe, unaware of the difficulties of conceiving such "slight" changes in an era much less sophisticated technically

3. There was a skilled technique of turning metal vessels and mirrors in the Bronze Age. E. Pernice, "Untersuchungen zur antiken Toreutik," Part III, "Die Metalldrehbank in Altertum," in *Jahresheft des Osterreichischen Archäologischen Institutes in Wien*, Vol. VIII, Part I, 1905, pp. 51-60.
4. Franz M. Feldhaus, *Die Technik der Vorzeit, der geschictlichen Zeit, und der Naturvölker*, Berlin, 1914. Article, "Drehstuhl, Drehbank."

than our own, or of the very doubtful historical method of assuming that a purely logical construction of events must therefore have actually occurred. We shall here present only the established facts and such interpretations as seem to be properly inferred from them.

For technical purposes the lathe can be taken to be a machine tool in which a workpiece rotating about an axis provided by two bearings, or their equivalent, has material removed by the cutting action of a single-point tool. For historical analysis, however, we are more interested in the industrial lathe, and in terms of what it can do in production. This is not to underestimate the development of the ornamental turning lathe, whose products were a blind alley for industrial development, but many of whose mechanisms proved to be of first importance for the lathe and its special forms, the turret lathe and the automatic screw machine.[5]

About 1800 the industrial importance of the lathe in metalworking comes to a climax with Maudslay. With his work we have two most important transitions—first, the lathe becomes the basic tool for producing precision machine parts of iron or steel; and second, the lathe becomes the principal means of producing these parts in industrial sizes and quantities.

But we should also ask, "Exactly how is an industrial lathe of these capabilities achieved technically? What elements are essential to an industrial lathe?" The industrial lathe has significance because it has the size and strength in all its parts necessary to machine large pieces of metal. It has a power supply adequate for heavy work, and means of applying this power to turning the workpiece and to moving the cutting tool. The industrial lathe must have precision, which means that it has its parts made of iron and steel, and certain of

5. The development of the turret lathe and the automatic screw machine will be treated in a later monograph in this series.

these parts must themselves be of precision design and construction – the guideways, the lead screw, and the spindle bearings. The industrial lathe has to have convenience in operation, so that the operator can produce at a profitable rate. An industrial lathe prior to 1850 needed flexibility, for methods of production did not permit the highly specialized and automatic machine tools required after the mid-nineteenth century.

All these elements were essential for the lathe to become, in the first half of the nineteenth century, the basic machine tool of industry. We shall trace their development in detail, in so far as the sources allow.

I The Primitive Lathe

FIRST TRACES OF LATHE WORK

THE FIRST LATHES

EARLY DRIVE OF THE LATHE

As with the loom and the potter's wheel, the first beginnings of the lathe must be inferred from such of its products as have come down to us. For we have numerous examples of work clearly done on a lathe of some sort at least half a millennium before we have even a representation of an actual lathe.

By far the greatest portion of early lathe work which has been preserved is in wood, but we do have important artifacts in stone and metal. However, these sources are very scanty, for only under especially favorable conditions can objects turned of wood resist the destroying influences of thousands of years. One could hope to find evidence in bas-reliefs or wall paintings were it not that craft work, except in the Egyptian culture, was seldom deemed worthy of illustration. And authors whose writings have been preserved mention the lathe at best only in passing and in general or mythological terms.[1]

The first steps in the development of the lathe can therefore be ascertained at only a few points.

FIRST TRACES OF LATHE WORK

In their tombs the Egyptians left such detailed illustrations and models of so many aspects of their daily life that one expects to find examples of turned work or even an illustration of a lathe. Certainly if the Egyptians of high antiquity had the lathe, we would have found some evidence of it. The bow drill appears in ancient Egypt in a bas-relief of about 2500 B.C.[2] and is frequently found

1. Pliny, *Natural History*, VII, 56, and XVI, 40; Vitruvius, X, 1,7,8; Philon of Byzantium, *Mechanics*, IV, 60,61. A very full list of additional references can be found in Hugo Blümner, *Technologie und Terminologie der Gewerbe und Künste bei Griechen und Römern*, Leipzig, 1879, Vol. II, pp. 331-334. Blümner's interpretations are not always correct, however.
2. G. Steindorff, *Das Grab des Ti*, Leipzig, 1913, Plate CXXXIII.

after that, but there is not a single representation of the lathe in Egypt until Hellenistic times. Yet we have clear evidence for the use of the lathe in other parts of the ancient world long before this.

In the second millennium B.C. we do find some objects which seem at first glance to have been turned. There are furniture legs found in Egypt and dating from the late New Kingdom which have been identified as turned. Closer examination, however, shows them to have been carved and polished, but clearly not turned.[3] Woodworkers are often shown but never at the lathe. In fact in old Egyptian there is no word for "turning" or "turned work." A survey of the prehistoric wooden and bone objects from the moors of central and northern Europe, as well as those of northern Italy, shows that these objects, too, were all carved until after 1000 B.C. Some archaeologists have been too ready to assume such objects to have been turned and seem surprisingly unaware of the perfection of work which can be done by patience and a hand skill inherited through many generations.

In pitgrave V of Mycenae (1100-1400 B.C.) there was found[4] a flat wooden bowl, which stood on high legs (Fig. 1). Because this piece shows no turned grooves, there is some question of its really being turned. However, its edge runs out to a rounded lip and in the bottom of the dish there is a hole, which has been carefully

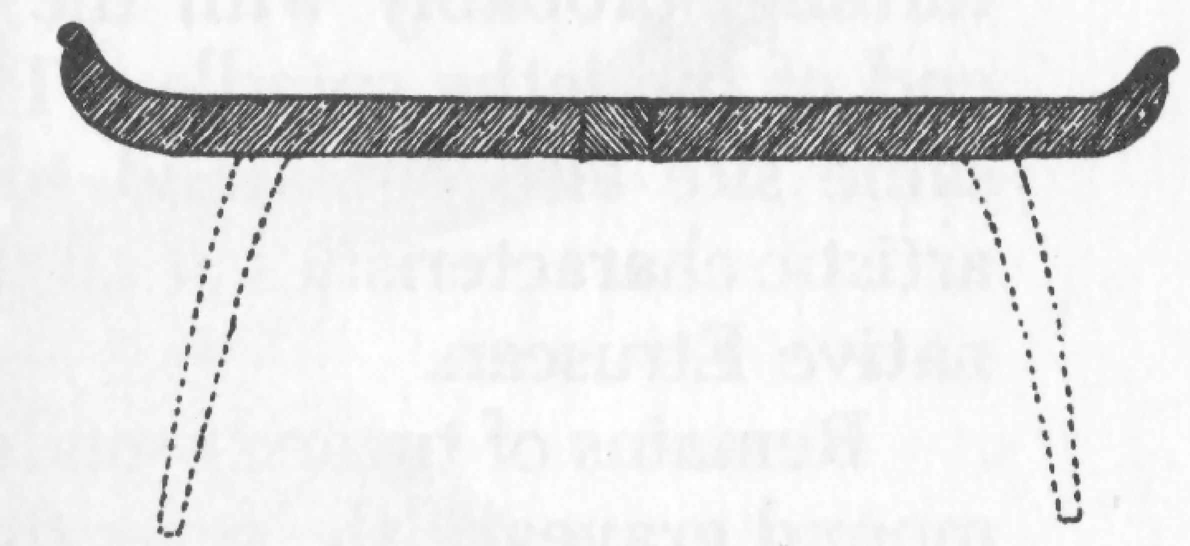


Fig. 1. Mycenean Wooden Bowl. (c. 1200 B.C.) *(Rieth-IPEK)*

3. G.M.A. Richter, *Ancient Furniture*, Oxford, 1926, Fig. 56; H.E. Winlock, *Private Life of the Ancient Egyptians*, New York, 1935, Fig. 5.
4. K.G. Karo, *Die Schachtgräber von Mykene*, Munich, 1930/1933, p. 153, Plate CXLVII.

plugged up. This would suggest that the bowl was turned by mounting the workpiece on a mandrel or at least on the spindle of a lathe. We shall see clear evidence of this technique in Egyptian wooden vessels certainly turned in Hellenistic times, and still later in Celtic England. Despite the much earlier use of the drill-borer and the potter's wheel, in these areas we have no objects which we can say with certainty were turned, until the early part of the first millennium B.C.

The oldest certain trace of lathe work we have is a fragment of an Etruscan wooden bowl[5] from the "Tomb of the Warrior" at Corneto (730-690 B.C.) Now in the Berlin Antiquarium, (Fig. 2) it shows clear evidence of

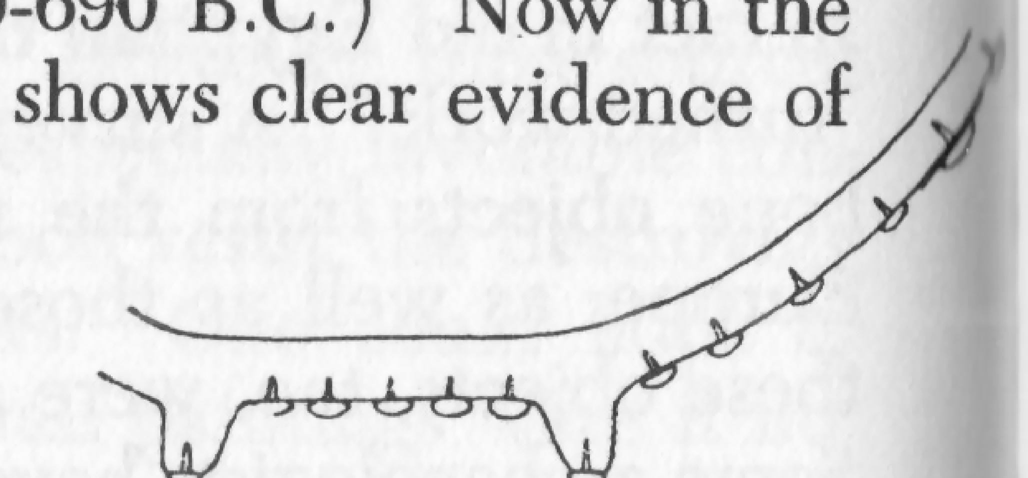


FIG. 2. ETRUSCAN TURNED BOWL.
(c. 700 B.C.)
(Rieth-IPEK)

rounding and profiling on its outer surface and of hollow turning, which would seem to indicate that there was by that time already a fairly well established technique of turning, probably with the workpiece mounted on the end of the lathe spindle. The "Bocchoris" grave of this same site also contained turned wooden vessels. The artistic characteristics of all this work show it to be clearly native Etruscan.

Remains of turned wooden vessels were also found in mound graves of the seventh century B.C. in Asia Minor. Korte found in one of the largest graves of Gordion "two flat wooden dishes whose edge had a type of decorative border which had been turned."[6]

In the sixth century B.C. we begin to find in the Etruscan world substantial numbers of turned ornaments for hairpins and turned amber beads, as well as nicely

5. David Randall-MacIver, *Villanovans and Early Etruscans,* Oxford, 1924, pp. 160-164.
6. G. and A. Korte, *Gordion,* Berlin, 1904, pp. 53 and 87.

worked wooden plates with turned base rings.[7] By the fifth century in the Crimea there are a number of turned wooden bowls and boxes, possibly imitating earlier similar objects in clay.[8] There is a double box made in one piece with separate cover, from Kertsch, which shows a highly sophisticated skill in turning, even if it does not indicate further technical progress.[9] These objects were all probably produced in this area.

Looking at the Celtic world north of the Alps we find that already in the sixth century B.C. the turner's skill had developed into a fine art. Preserved by the moisture of an underground bog and the large bronze grave vessel in which it was placed, was a magnificent turned wooden bowl (Fig. 3). It was found by Naue[10] in a late Hallstatt mound grave at Uffing in Upper Bavaria. At the moment of excavation, the bowl was in perfect condition and

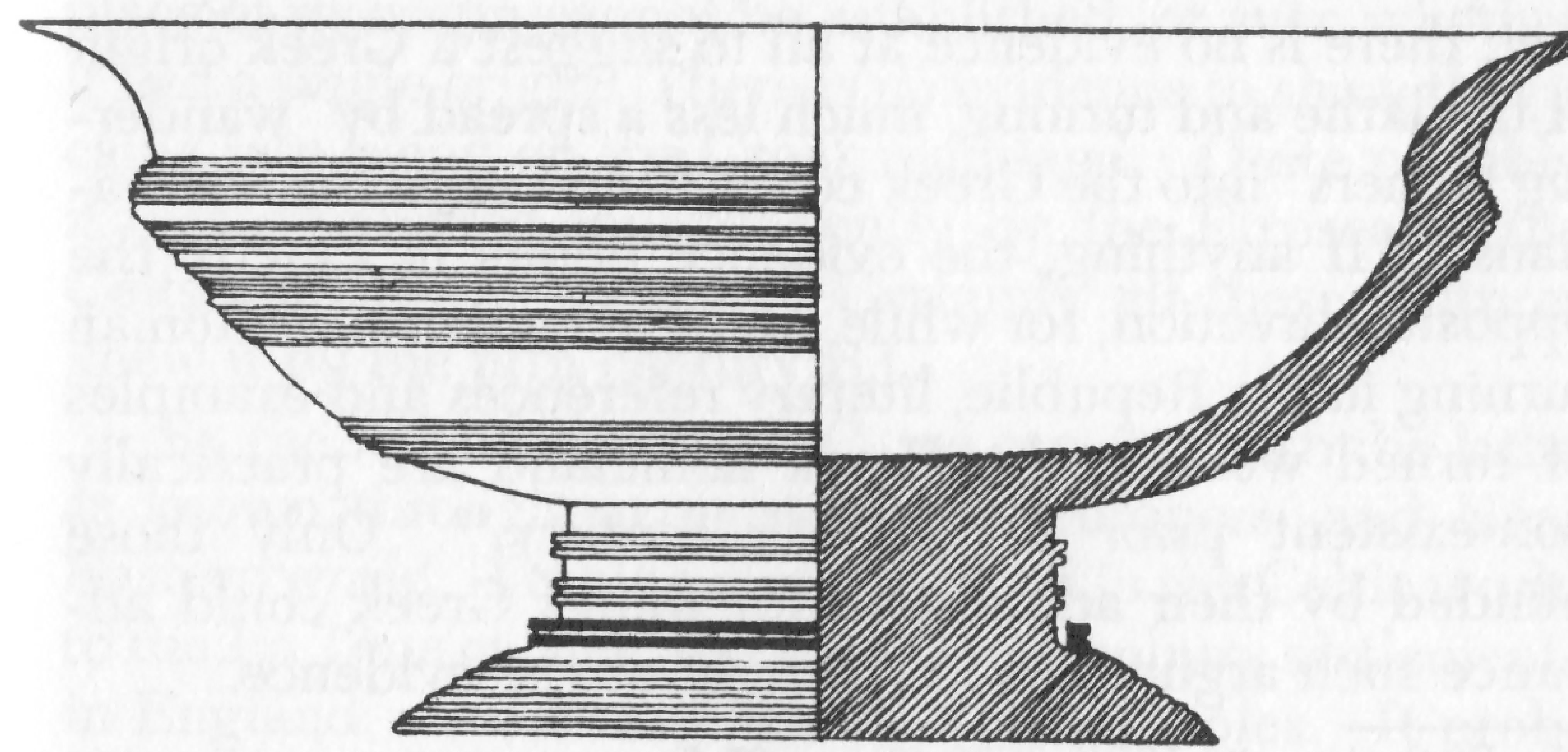


FIG. 3. CELTIC TURNED BOWL. (Sixth Century B.C.)
(Reproduced. *Rieth-IPEK*)

7. A. Zannoni, *Scavi della Certosa,* Bologna, 1876, p. 61.
8. Carl Watzinger, *Griechische Holzsarkophage,* Leipzig, 1905, p. 37 ff. Mikhail I. Rostowzew, *Skythien und der Bosporus,* Berlin, 1931, Vol. I, pp. 186, 258, 289, 561.
9. Karl Schefold, *Untersuchungen zu den Kertscher Vasen,* Berlin and Leipzig, 1934, p. 59.
10. Julius Naue, *Die Hugelgräber zwischen Ammer- und Staffelsee,* Stuttgart, 1887, pp. 61 ff and pp. 142 ff, Plates 35, 6 and 6a.

scarcely warped. Inadequate archaeological methods of preservation nearly destroyed it, and today it is bent and split. Fortunately Naue did make an exact drawing of it, so that it was possible for Rieth to have it reproduced.[11]

One cannot, however, accept Rieth's attempts to infer, from this bowl and the methods used to reproduce it, a detailed description of the technique by which this masterpiece was turned. Nor can one accept his even more elaborate arguments to prove that this bowl is Greek in its origin and that therefore turning originated in the Greek world and spread from the Greek colonies to the Celtic and Near Eastern worlds. The very high quality of the work to be found in both the Etruscan and the Hallstatt cultures gives us every reason to suppose that they were quite capable of artistic work on this high level, independent of any outside inspiration or teaching. In fact, there is no evidence at all to suggest a Greek origin of the lathe and turning, much less a spread by "wandering turners" into the Greek colonies and so to the "barbarians." If anything, the evidence points in exactly the opposite direction, for while we have evidence of Roman turning in the Republic, literary references and examples of turned work in the Greek homeland are practically non-existent prior to the 5th century.[12] Only those blinded by their admiration for things Greek could advance such arguments in the light of the evidence.

11. Rieth, *loc. cit.*, *IPEK*, 1939-40, pp. 85 ff.

12. It is at least suggestive that prior to the fifth century B.C. (In Euripides, *Bacchae*, 1067. Strabo's quotation, *Geography*, X, 470, of a reference by Aeschylus to the lathe is open to some doubt.) there are no references in Greek literature to the lathe or to turning, but after that time they become fairly frequent. Blümner's references to mention of turned work in Homer are based upon a forced translation of δινωτά (carved or inlaid in circles or spirals, such as were common in the Mycenean and other Bronze Age cultures. See Julius Naue, *Die Bronzezeit in Oberbayern*, Munich, 1894), or on taking this word out of context where it refers to objects not necessarily turned and in some cases clearly not turned at all. (This error is repeated in Liddell and Scott, *Greek-English Lexicon*, Oxford, 1940.) From the fifth century B.C. on, the Greeks used the term

The technique of the turner of this bowl had certainly developed to the point of fancy. A thin ring, profiled in itself, has been turned loose from the base so that it is free to move, and one is reminded of the ornamental turning work of 2000 years later. But the fashion of free rings occurs also in Hallstatt metal vessels, and similar engraved bands of lines on the body are to be found on late Hallstatt bronze vessels.[13]

The nature of the lathe and the technique of turning used to produce this delightful little bowl remain unknown to us, but it clearly indicates a very high level of turning skill, though the lathe on which it was done may actually have been quite primitive.

It seems quite clear then that the lathe was certainly in use as early as the eighth century B.C., probably as early as 1000 B.C., and possibly even in 1200 B.C. The place of its origin cannot be established, or even whether it had a single origin. There is no evidence to show that it came into being on the Greek mainland. Quite possibly it was discovered independently by the Etruscans, the Celts, and in the Crimea. Certainly all these cultures knew it by the fifth century B.C.

By the second century B.C. we can establish the lathe as known throughout most of the European and Near Eastern world. Turning clearly spread in the Celtic world to the La Tène culture and to the Glastonbury settlements in England, as well as to the Teutonic peoples. It probably passed from the Etruscans to the Romans. And it is possible that it spread from the Crimea down into

τορνος in referring to the lathe, and it is significant that δινωτά is not used in this connection again, despite their certain familiarity with it. Some scholars have even insisted that τορνος does not refer to turning, but to sculpture or to carving. In the preface to his *L'art de tourner*, Plumier suggests that a reference in the *Song of Solomon* (c. 1014 B.C.) to "arms smooth as though turned on a lathe" proves a Judean origin of the lathe and a subsequent spread into Greece and Rome. I have been unable to find this reference. If not a later interpolation, it would be of great interest.

13. E. v. Sacken, *Gräberfeld von Hallstatt*, Wien, 1868, Plates 12,13,17.

Egypt and to Greece. The details of this spread cannot be established, despite Rieth's attempts to deduce a simple path leading from the Greek homeland to the Greek colonies, and so to the Romans and to the "barbarians."

Scattered turned wooden bowls are found in the area of the Teutonic peoples from the third century B.C.; for example, at Hjortspring in Denmark[14] where turned boxes and plates were found. But the Teutons remained at this time mostly wood carvers; their infrequent turned work was quite crude. Many Germanic peoples probably remained unacquainted with the lathe until the second half of the first century B.C.,[15] or until the time of the Great Migrations.

In the Celtic settlements of the La Tène culture (500 B.C.-100 A.D.), which followed the Hallstatt, we find a number of turned wooden bowls as well as many other useful objects mechanically rounded.[16] This culture also turned the spokes and hubs of wagon wheels.

Prior to the third century the lathe had come to Egypt, for we find the first representation of this device on the wall of a grave of that century (Fig. 8). We have turned salve flasks in wooden sarcophagi of the fourth century from Abusir[17] and actual examples of Hellenistic sofas with legs clearly turned. In the Egyptian section of the Berlin National Museum we can see several wooden vessels from Hawara (2nd century B.C.) in lower Egypt. These have the characteristic hole in the center of their bottoms, subsequently plugged with a wooden pin, and suggesting mounting of the workpiece on a lathe spindle acting as a mandrel. A series of little fourth century

14. Article "Hjortspring" in *Reallexikon der Vorgeschichte*, Vol. V, plate 100.
15. Walther Veeck, *Die Alemannen in Württemberg*, Berlin and Leipzig, 1931, p. 17ff., Plate I (2,3,4).
16. P. Vouga, *La Tène*, Leipzig, 1923, p. 87 and Plate XXIX.
17. K. Watzinger, *loc. cit.*, p. 37 ff.

boxes with turned lids from the Etruscan settlement near Praneste are preserved in the Villa Giulia in Rome. Many of these also have the same characteristic plugged holes.

The settlement artifacts preserved by the peat of Glastonbury in England give us most important information of the early techniques of turning, for these people not only turned in wood but in soft stone. We have therefore from this area perfectly preserved artifacts of the highest importance.

The turners of the Glastonbury Lake Village (100 B.C. - 50 A.D.) have left us spoiled or unfinished examples of their work which permit a sure determination of the techniques they used.[18] Turned wooden wheel hubs similar to those shown in Figure 4 have been found in other Celtic sites, for example at Dejbjerg in Denmark, but this example is unfinished and so can tell us much more. The slots for the wheel spokes have not yet been cut, nor has the hole for the axle been bored. But the dimensions of the hub and the fact that spindles are present on *both* ends of the piece give us assurance that this was *turned between centers,* the first clear evidence we have of this technique.

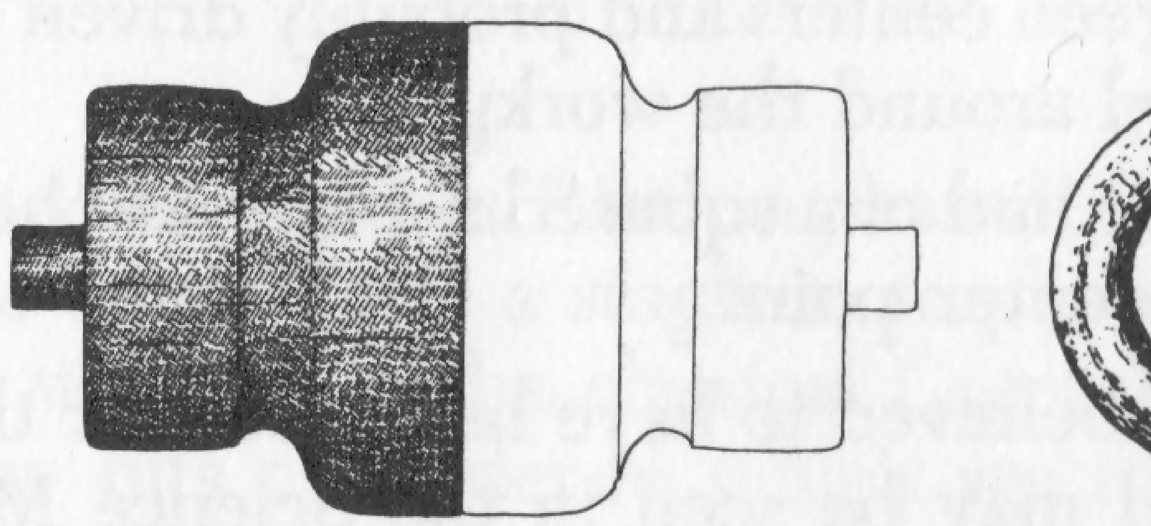


FIG. 4 UNCOMPLETED TURNED WHEEL HUB FROM GLASTONBURY. (First Century B.C.) *(Bulleid and Gray)*

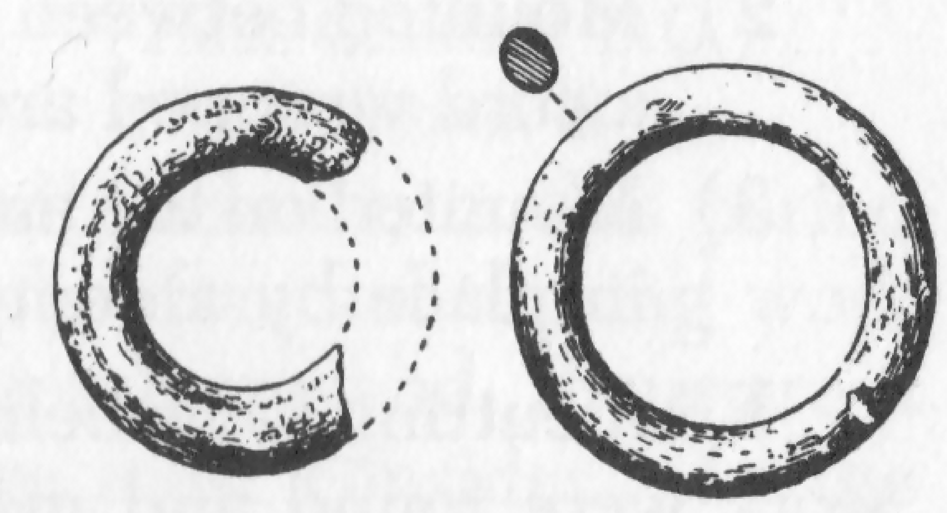


FIG. 5. CELTIC ARM BANDS OF SHALE. (First Century B.C.) *(Bulleid and Gray)*

18. Arthur Bulleid and Harold Gray, *The Glastonbury Lake Village*, Glastonbury Antiquarian Society, 1911, pp. 254-265, 336 ff., Figs. 49,53,54, and 110.

The Glastonbury villagers were fond of a kind of ring turned of the soft Kimmeridge shale. Examples of these in various stages of construction, as well as the stock left behind, are most interesting. Figure 5 shows the finished condition of these rings. Figure 6a shows a roughly prepared disc perforated to be mounted on a mandrel between centers or driven onto the outer end of the lathe spindle. The portion which remains after the ring is turned free, working from both faces, is shown in Figure 6b. In Figures 7a and 7b we see a different technique. Here a squared hole was cut part way into the disc blank for driving the work, and a centering hole provided on the opposite face for supporting the outer end of the workpiece and holding it onto the squared end of the lathe spindle. In Figure 7a the ring has been cut free; perhaps two have been made from this piece of stock. In Figure 7b the turner cracked off a piece of shale, spoiling the work, but thereby leaving us clear evidence of his whole technique of turning both faces. At Glastonbury we can be sure that the turner had several methods of mounting his work on the lathe:

1) Forced onto a mandrel or onto the lathe spindle.
2) Mounted between centers and probably driven by a cord wrapped around the workpiece.
3) Mounted on the end of a squared spindle and held in place by a center point.

Flint cutting tools believed to have been used for this work were found and may be seen in the Science Museum, London.

Just how much earlier these techniques were known we cannot say, much less where they originated. Method (1) may possibly have been used at Mycenae in the 12th century B.C. Method (2) is clearly shown in Egypt in the third century B.C. (See Fig. 8). Method (3) seems to have been unique with the Glastonbury turners.

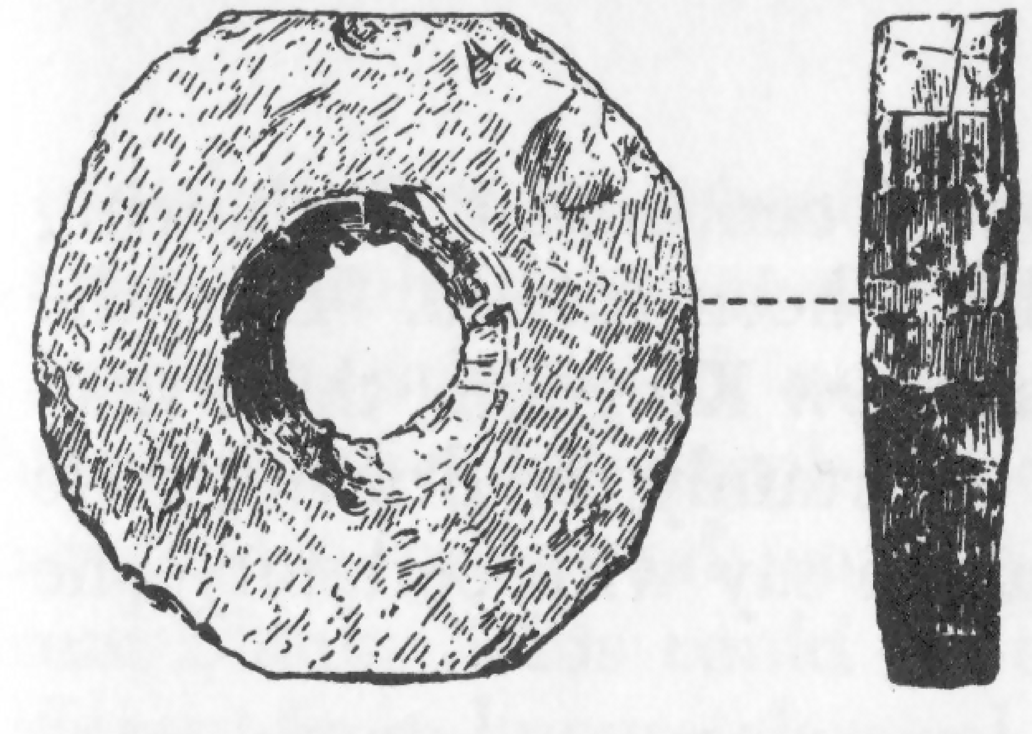


FIG. 6a. ROUGHLY SHAPED BLANKS FOR CELTIC ARM BANDS.
(First Century B.C.)
(Bulleid and Gray)

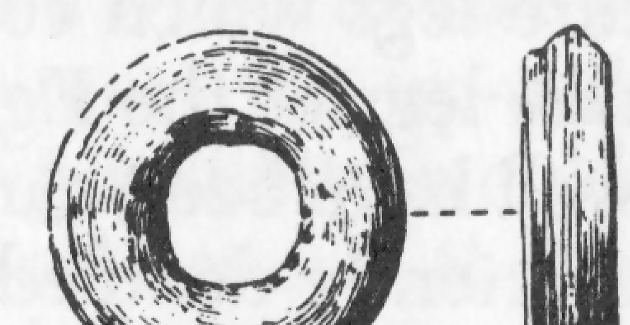


FIG. 6b. BLANK FROM WHICH AN ARM BAND HAS BEEN TURNED FREE.
(First Century B.C.)
(Bulleid and Gray)

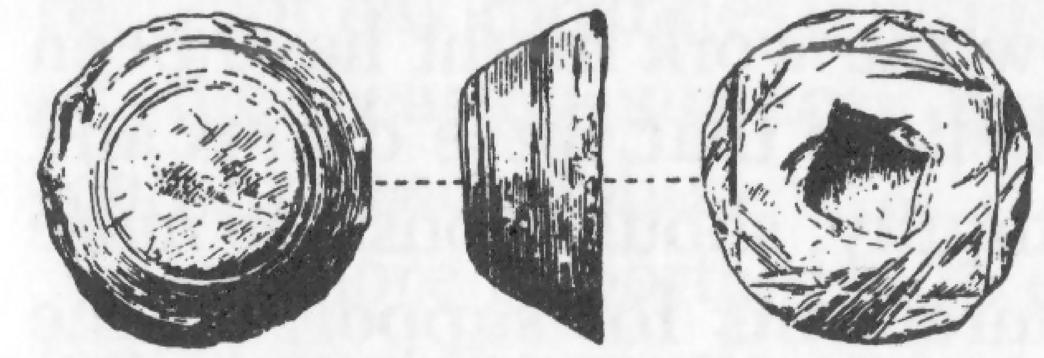


FIG. 7a. SQUARED HOLE FOR DRIVING THE WORKPIECE.
(First Century B.C.)
(Bulleid and Gray)

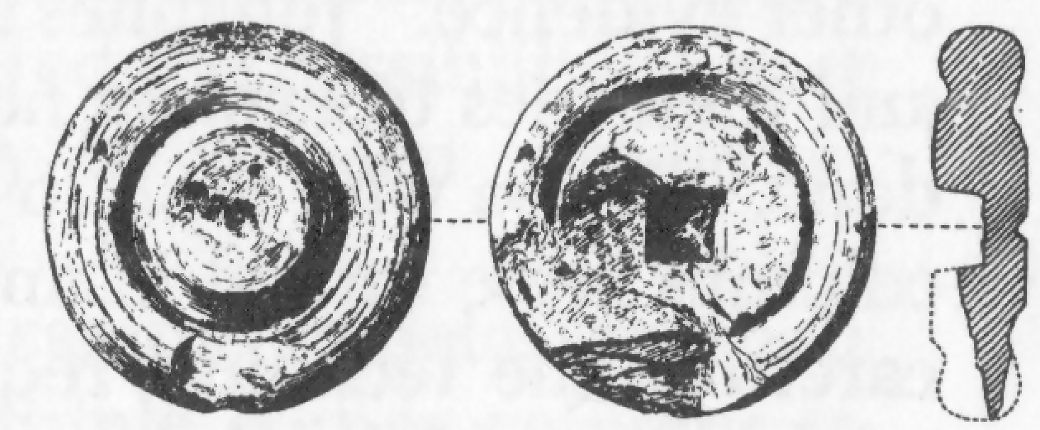


FIG. 7b. SHALE ARMBAND FRACTURED IN TURNING, METHOD OF DRIVE AND CUTTING RING FREE.
(First Century B.C.)
(Bulleid and Gray)

Although, as Rieth repeatedly admits, in this period we do not have a single example of actual turning work in wood from the classical Greek homeland, there are a few bits of evidence which we must consider. In the sixth century we do find a few turned ivory heads on hairpins from Ephesus,[19] but they are not very different from those to be found in Celtic areas in the same century.[20] And there are drawings on the geometric am-

19. D.G. Hogarth, *Excavations at Ephesus,* London, 1908, Plates 4,6, and 33.
20. F.A. Schaeffer, *Les Tertres funéraires de Haguenau,* Imprimerie de la Ville Haguenau (Alsace), 1926, Vol. II, Plate 28.

phorae of the eighth and seventh centuries B.C. showing furniture legs which could have been turned. Like the furniture legs of the Egyptian New Kingdom, these may very well have been carved. Certainly the drawings are not sufficiently detailed for us to say with certainty one way or the other.[21]

There then remains the supposed turning of temple column drums in stone, especially those of the sixth century Hera temple of Rhoecus on Samos which have been carefully studied by Johannes.[22] The material of all these drums is a very fine compact limestone which could be easily worked, and their profiles are such that one could accept them as turned if one did not take into account other evidence. Johannes assumes that they were turned and then tries to explain how the work might have been done. Those who wish to believe that these drums and columns were turned in antiquity, should consider more carefully the technical requirements for support of the workpiece and for the cutting tool, as well as the source of power and the means of applying it to turning these heavy weights at cutting speeds. Johannes rejects on practical and technical grounds the theory that these drums were mounted between centers and turned with their axes horizontal, despite Pliny's statement that "the drums in the workshop were balanced in such a manner that a boy could give them the rotation necessary for turning."[23] He tries to explain the observed characteristics of these drums and the tori associated with them as produced by mounting them with their axes vertical on

21. C.L. Ransom, *Studies in Ancient Furniture,* Chicago, 1905, pp. 24,82; G.M.A. Richter, *Ancient Furniture,* Oxford, 1926, Fig. 57.

22. Heinz Johannes, "Die Säulenbasen vom Heratempel des Rhoikos," in *Mitteilungen des Deutschen Archäologischen Instituts (Athenische Abteilung),* Vol. 62, 1937, pp. 13-28.

23. Pliny, Book 36, 90. Pliny's statement has been seriously doubted, yet modern calculations by Professor Richard S. Hartenberg indicate that Pliny may have been quite right. But Pliny was writing in the first century A.D.

a slowly rotating wheel, something like the potter's wheel. But he does not explain how a wheel to take such a load was supported, nor how to meet the up-ending thrust of the cutting tool. Another possibility would be to rotate a framework carrying a tool around the fixed drum blank. This could be done by methods not too different from known classical methods of rotating large grain mills in later times, and would fit all the data we have on the drums. But we have no reliable historical evidence for such a theory, either. Far more likely still is that these drums were not turned at all, for despite Johannes' assertion, we do not know that these drums ever were cylindrical "exact to the millimeter," nor with the disintegration of their soft limestone can we ever be sure. Nor has Johannes considered the possibility that at least the bearing surfaces may have been ground in place to fit each other.

Even more important is to examine in detail the half columns and the single and multiple corner columns to be found in many places in the ancient world. All the arguments for turning of free columns apply equally to these architectural devices. One would therefore assume them to have been turned were it not for the fact that the cross sections of these single pieces of stone show such a method to be impossible.[24] For this work the only possible explanation is patient hand skill of the stone cutter, perhaps assisted by a framework mounted to rotate around the drum blanks and carrying a templet to guide hand carving. Whatever technique was used to make these special columns was equally adequate for free columns. Certainly we are not forced into assuming that any stone columns were turned prior to Pliny's day, and templet-guided hand carving offers a simpler explanation which will fit all the facts.

24. O. Paret, *Die Römer in Württemberg,* Stuttgart, 1932, Part III, Figs. 21,23,24.

In all this material one can hardly find evidence for a Greek origin of the lathe.

The Romans clearly had the lathe and a developed technique of using it, probably derived from the Etruscans. At any rate their turned boxes with covers seem to be an extension of Etruscan types, as do their clearly turned legs for furniture. We have turned wooden plates and parts of furniture from Herculaneum and simple turned wooden boxes from North Africa. There is no evidence, however, to support Rieth's contention that the Romans turned in alabaster or that their other turned objects were mass produced, despite the fact that turned products, like so many other products of the Roman genius, show a considerable uniformity and some artistic decline.

We also have evidence for metal turning at this time. In his *Belopiika* we find a passage[25] of Philon of Byzantium in which he describes turning the surfaces of bronze pump cylinders and their pistons for the water organ and for compression cylinders in a large war engine. Philon says that the fit of the piston in the cylinder was so good that no water could escape under any pressure! Turning of metal to this order of accuracy seems unlikely, and if we are to take Philon's statement at its face value some fitting technique must have been used, perhaps grinding or lapping.

By the second century A.D., then, turned products of wood and other materials were to be found throughout the world of antiquity.

THE FIRST LATHE

Speculation in history without even a trace of historical fact is useless and misleading. Therefore no attempt will be made here to speculate on the origin of the lathe in either the potter's wheel or in the bow drill. The ingenious theories that either of these two devices could "easily" have been converted into a lathe remain unconvincing. Their arguments all assume a high level of mechanical ingenuity and technical intelligence on the part of the people who made this great invention. Yet of all the cultures of the ancient world, the Egyptian certainly had both these qualities in as high a degree as any other people. How then can these theorists explain the *fact* that the Egyptians definitely had both the potter's wheel and the bow drill[26] prior to 2500 B.C., yet we find not a trace of evidence that they had the lathe prior to the fourth century B.C.? If this people, so remarkable in so many technical matters, did not make the transition from the bow drill or the potter's wheel to the lathe in over 2000 years, are we to assume that other people, known to be less sophisticated technically, did so as a matter of course?

From the examples of lathe work preserved to us we have already established the fact that a lathe of some sort was surely in use by about 700 B.C. We may now ask, what kind of a lathe was it? What were its principal features, and how did it operate? Prior to the third century B.C. we have only the very vague characteristics which we have shown can be inferred from early turning work.

In Figure 8 is shown the earliest representation we have of a lathe. It was carved in low relief on one of the walls of an Egyptian grave of the third century B.C., the grave of Petosiris.[27] In examining this picture one should remember the Egyptian pictorial convention by which objects in the horizontal plane are frequently rotated into the vertical plane for clarity, in the absence of a technique of perspective drawing.

25. Philon, *Mechanika,* IV, 60,61.

26. The early origins of drilling will be considered in a later monograph on the *History of Boring and Drilling Machines.*

27. G. Lefebvre, *Le tombeau de Petosiris,* Cairo, 1923/24, Plate 10.

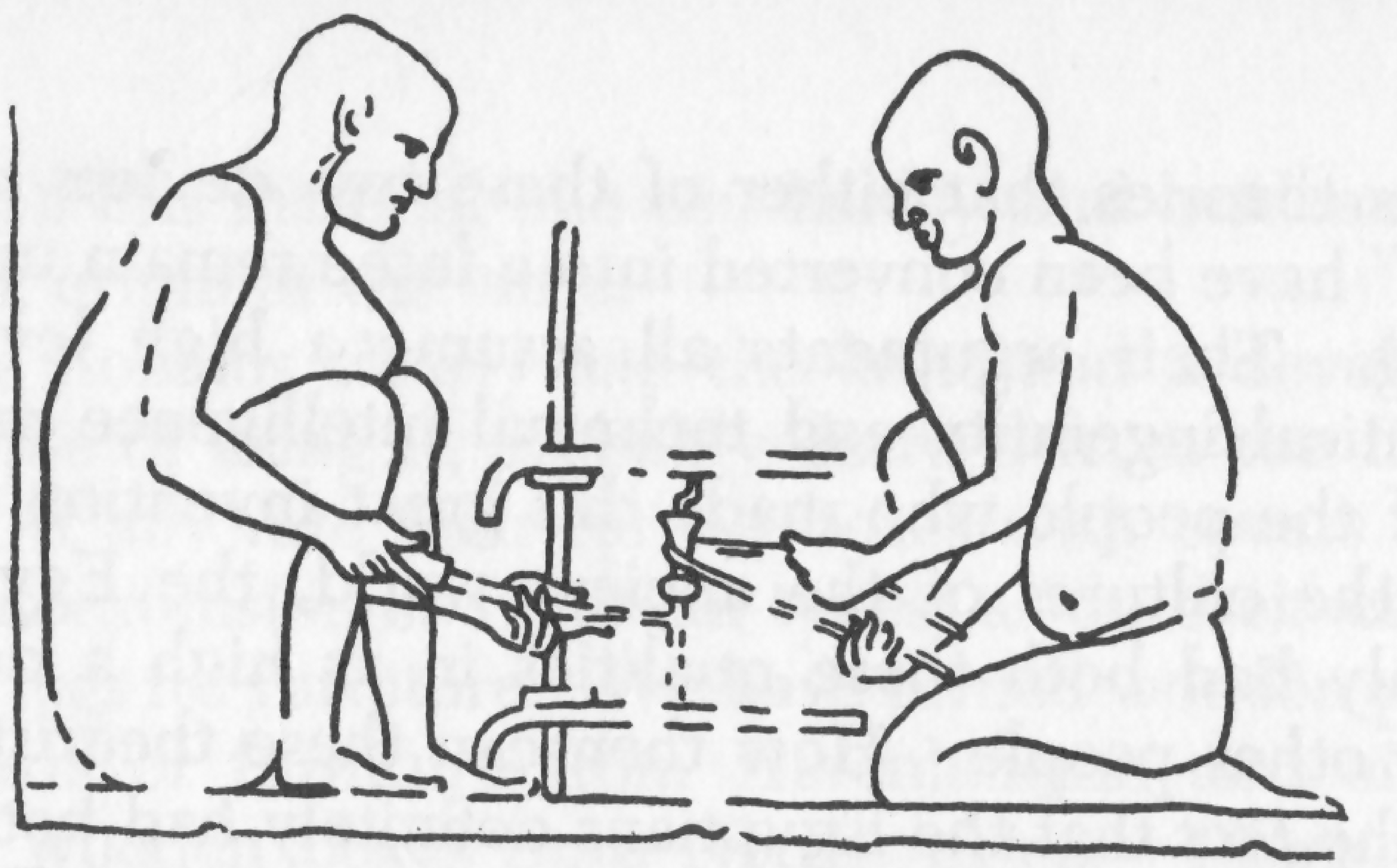


FIG. 8. THE LATHE IN THE THIRD CENTURY B.C.
(Lefebvre)

As is still common in both the Near East and the Far East, the two workers kneel or squat at their work. We can clearly see the turner at the left and his assistant at the right.

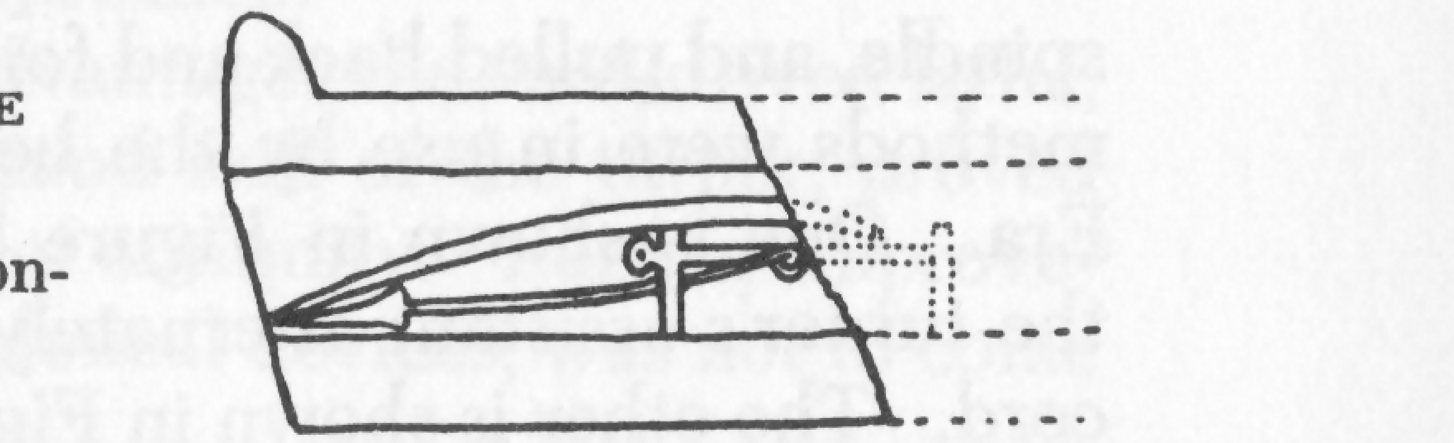
The frame of the lathe appears to have consisted of two longitudinal bars, of which one is probably hidden behind the assistant. At right angles to this primitive lathe bed are two other bars which act as head and tailstocks. One or both of these must have been movable along the lathe bed, to permit the turner to do work on pieces of different lengths, for both stocks seem to have been secured to collars which could slide along the front bed bar. The purpose of the curious curve on the ends of the stock bars is not clear. Even though such an arrangement would be less rigid, it is possible that there was no rear bed bar and that the curved ends of these stocks were driven into the ground.

The workpiece is clearly mounted between centers, and the bas-relief is not so badly damaged that we cannot make out the use of at least one offset center point. The turner has a cutting tool with a handle, and clearly rests the tool on the front bed bar for more rigid support. The center line of the workpiece seems to be rather far from the supporting point of the tool, but we must make allowance for some artistic license.

What appears to be a wooden furniture leg is just being turned, and is put in rotation by a two-hand cord drive worked by the turner's assistant.

A device from the gravestone of a gem-engraver of Philadelphia from the time of the Roman Empire (Fig. 9) is probably not a lathe, but it can throw some light on what another type of lathe may have looked like in this period.[28] Here we have the head and tailstocks on the end of stakes driven into the ground. Each stock has a hole which acts as a bearing for a lathe spindle. In a lathe the work to be turned would be mounted on the end of this spindle, although in gem cutting the cutting head would be on the end of the spindle and the work held in the hand. The spindle is rotated here by a cord worked by a bow.

FIG. 9. GRINDING DEVICE OF ROMAN TIMES.
(Kantoleon, partially reconstructed by Feldhaus)



Lathes not very different from this can be observed in many parts of the world today, in Asia Minor, Persia, and Afghanistan. On them hand skill produces some very fine turned work. Until the opening of Japan to the West, metal vessels were still turned in that country on similar devices.

Taking this evidence together with what can be inferred from the Glastonbury artifacts, we can be quite sure that by the second century B.C. at least two types of lathe were in use, one in which the work was mounted (either directly or on a mandrel) between centers held in a frame which also served as a rest for the turner's hand-held tool. The other early type of lathe had a

28. Alexander E. Kontolon, "Epigraphika" (Section 2), in *Mitteilungen des Deutschen Kaiserlichen Archäologischen Instituts (Athenische Abtheilung),* Athens, 1890, Vol. 15, pp. 333-334.

spindle carried on bearings in stocks, and the work was mounted on one end of this spindle, either by being driven on to it or by the use of several sharp points set in the end of the spindle. Both types were driven by a reciprocating cord.

EARLY DRIVE OF THE LATHE

Most accounts of the early drive of the lathe are hopelessly confused by making a potpourri of historical evidence, ethnological examples, and a bewildering binder of kinematic theory. Let us merely examine the actual historical evidence and the technical requirements implied in it.

It is quite clear that these early lathes were driven by a cord wound around the workpiece, or around the lathe spindle, and pulled back and forth by some means. Two methods were in use by the beginning of the Christian Era. One is shown in Figure 8 and consists of having the turner's assistant alternately pull on the ends of the cord. The other is shown in Figure 9, and utilizes a bow by which the ends of the cord are stretched and pulled back and forth. Both methods result in an alternating rotation of the workpiece. Since the turning tool will cut in only one direction, the turner must coordinate the action of the tool with the changing direction of rotation of the workpiece.

Each of these methods has certain advantages. The simple cord leaves the turner with both hands free to control his tool, a rather difficult task with the alternating revolution of the work. But he must have an assistant or apprentice.[29] The use of the bow cord has the advantage that the turner can drive the work with one hand while he controls the tool with the other, either singly or in combination with his feet. For the actual technique of turning with the bow-driven lathe in antiquity we have no historical evidence at all. Nor do we have any evidence for use of the feet to control the tool in any operation in antiquity, despite the fact that they are frequently so used today in the East.

The alternating rotation provided by the usual cord drive not only requires skillful manipulation of the cutting tool, but also loses half the working action, and it produces a rather jerky motion, which the skill of the turner must control. The more one examines the objects made on these crude lathes, the more one must admire the hand skill of these craftsmen.

Despite its many disadvantages the cord-driven lathe, taken together with the hand skill of the turner, proved satisfactory for the needs of antiquity. Further improvement, as with so many technical devices, was not to come until medieval times.

29. We can here ignore the use of the customer to operate two treadles in a leg pit below the lathe, which is found in some parts of the world today, for we have no evidence for its use in antiquity. Nor do we have any reason to suppose that the ancient world knew of the use of the loose bow drive by means of which the workpiece can be kept rotating continuously in one direction.

II The Lathe Becomes a Machine Tool

THE LATHE IN THE GUILDS AND IN THE MONASTERIES

LEONARDO DA VINCI AND HIS FOLLOWERS

THE ORNAMENTAL TURNERS

COMPLEX DEVICES

THE LATHES OF THE CLOCK AND INSTRUMENT MAKERS

PRECISION

THE LATHE BECOMES A MACHINE TOOL

As has been ably pointed out,[1] whatever the Dark Ages may have been politically, intellectually, or artistically, there is no reason to assume a corresponding decline from the high level of Roman technology and good reasons to expect important innovations, especially by the time of the high Middle Ages. We shall therefore not be surprised to find that the lathe, contributed by the "barbarians" and spread throughout the ancient world largely by the Romans, persisted as an important tool throughout the medieval period. And this era, technologically fruitful in so many ways,[2] made most important contributions to the development of the lathe. At least four are significant – (1) the use of the spring-pole-and-treadle drive; (2) the transformation of the lathe bed and its stocks into rigid substantial structures; (3) the introduction of continuous motion drive of the workpiece; (4) the appearance of the first device for holding and controlling the cutting tool mechanically.

THE LATHE IN THE GUILDS AND IN THE MONASTERIES

Toward the close of the Roman period we have evidence that the lathe was still in use, then clearly in the construction of mechanisms, for about 362 A.D. Oribasius tells us that the bodies of screws and other parts were being turned on the lathe.[3]

As early as 757 Bishop Joseph of Freising mentions the turners in Bavaria. That turning was then an honored craft is indicated by the fact that the turners are listed immediately after the favored iron workers.[4] In the ninth

1. Lynn White, Jr., "Technology and Invention in the Middle Ages," in *Speculum*, XV, 2, (1940), pp. 149-150.
2. Friedrich Klemm, *Der Beitrag des Mittelalters zur Eutwicklung der Abendlandischen Technik*, Wiesbaden, 1960.
3. Angelo Mai, ed., *Classici autores e codd. Vaticanis*, IV, 126 (Oribasius 49, 347-348).
4. Meichelbeck, *Historia Frisingensis*, I, n. 4.

century the *Capitulare de Villis* mentions "tornatores" among the craftsmen.[5] And in 820 the plans of the monastery of St. Gallen showed[6] a room set aside for the "tornatores." On many medieval miniatures and works of art are pictured turned chairs, reading stands, and other useful objects clearly the products of the turner's art.[7] We can then be quite sure that from Roman times there was no break in the use of the lathe for turning wood and soft metals.[8]

We have already seen some of the difficulties with the early cord drive of the lathe. Like the potter and weaver, the turner would, of course, like to be able to work alone and to have both hands free to control his tools. In Western Europe the whole tendency of handicraft has been to work in a standing position or at least seated erect at a bench and not, as in antiquity and in the East, to sit, squat, or kneel on the ground. Nor does Western man ever use his feet for exact control of a tool, as is common in the East. Although the origins and causes of these customs are not yet satisfactorily explained, the facts are real enough. One would therefore expect some changes in the lathe to occur as it spread in Western Europe, especially in the means by which it was driven.

The spring-pole-and-treadle drive probably came in

5. "Capitulare de Villis Imperialibus" in *Monumenta Germaniae Historica*, Legum, Tom. I, Ch. 45 and 62 (pp. 184-185).
6. Ferdinand Keller, *Bauriss des Klosters St. Gallen*, Zurich, 1844, Plan and p. 30.
7. For example: British Museum, Greek MS. Add. 28815, fol. 76v and 162v (10th century); Louvre, Bas-relief of St. Matthew from Chartres, (12th century); British Museum, Sloan MS. 3983, fol. 11 and 17 (14th century).
8. For Germany see M. Heyne, *Das altdeutsche Handwerk*, Strassburg, 1908, Ch. I, *passim*. For France see the *Livre des Métiers de Paris* drawn up 1258-1270 for Etienne Boileau, printed in R. de Lespinasse and F. Bonnardot, *Les Métiers et Corporations de Paris, XIIIe Siecle*, Paris, 1879, XI-8, XLIII-6, XLVII-8. Also the taxrolls of 1292 and 1300 and the Dictionary of Jean de Garland of the second half of the eleventh century printed in H. Geraud, *Paris sous Philippe le Bel*, Paris, 1837.

to meet these needs and marks the next great advance in the technical development of the lathe. Apparently its possibilities for improved turning were recognized fairly quickly, for after its first appearance it spread very rapidly. Turning in wood was done well down into the 19th century on pole lathes essentially the same as those we see in the 13th century, and in some parts of the world lathes of this type can still be found in daily use.

In the pole lathe (Fig. 12) we still retain a cord drive, but one end of the cord is now fastened to the end of an elastic wooden pole secured above the lathe. The other end of the cord is attached to a treadle hinged to the floor. When the turner steps down on the treadle with one foot, the work is rotated rapidly in one direction. When his foot is lifted, the elasticity of the pole pulls back the cord and the work rotates in the opposite direction. Alternating motion of the workpiece is thus still retained. Neither the speed of rotation nor the number of revolutions per alternation is increased by the use of the spring-pole-and-treadle, although the available power is probably somewhat greater. This type of lathe is certainly much more convenient than the simple cord or the bow drive. More important, it marks the transition to a drive of the lathe by a mechanical linkage, whose action can be coordinated with convenient control of the cutting tool.

Despite clear traces of the widespread use of the pole lathe in the Middle Ages, we have no certainty as to where and when the spring-pole-and-treadle drive first appeared. The only clue the author has been able to find of its medieval technical features prior to the 13th century is in Theophilus Presbyter[9] who describes, about 1130, a device for making the cores for casting bells and for pewter tankards. For these cores he constructed a heavy temporary device, saying "make a lathe in the

9. Theophili Presbyter, (Rugerus), *Libri III De Diversis Artibus,* III, 61, 81, 85 and 88.

same manner as trenchers and other wooden vessels are turned." In this and in a lathe for turning the clay core for a censer he provided a direct crank drive, and the latter lathe had a tool rest adjustable in steps to support sharp cutting tools. Another "device made like a lathe" was also turned by a crank to make soldered copper organ pipes appear to have been turned. A metal cutting lathe is also described for finishing cast pewter vessels mounted between two posts, one of which is moveable, and rotated by "a strap being placed around the wood, and the boy who draws it being seated. . . ." Here is clear evidence that the lathe was in common use in Theophilus' day. Moreover, the fact that he twice refers to its being turned by a boy seated, would suggest that he did not know of the spring-pole-and-treadle lathe and that it perhaps appeared first in the second half of the 12th century. The first illustrations appear in the 13th century and show the pole lathe as clearly in use in turning shops associated with monasteries or churches.

FIG. 10. THE SPRING-POLE-AND-TREADLE LATHE IN THE THIRTEENTH CENTURY. *(Aclocque)*

A stained glass window at Chartres[10] given by the turners of the local guild in honor of their patron Saint Julien, is the earliest of these representations of the pole

10. Geneviève Aclocque, *Les corporations, l'industrie et le commerce a Chartres,* Paris 1917, Plate III.

lathe (Fig. 10), but is not as clear or detailed as we would like. But we can see the workpiece supported between centers, and with the turner's hand resting upon it as he sits on a bench at his work. We can see only the tip of the spring pole, but the cord drive is clear, even if it is not shown as wrapped around the workpiece. The details of the treadle are not clear,[11] but the presence of only a single cord and other representations (Figs. 11 and 12) make us sure that it had only a single pedal.

FIG. 11. THE POLE LATHE IN THE THIRTEENTH CENTURY. *(Bib. Nat.)*

Our next picture of the pole lathe (Fig. 11), being a manuscript miniature,[12] is much clearer. Here the turner is also seated at his work to prevent the motion of his left leg on the treadle from interfering with his control of the tool. The cutting tool already has a long handle held in the position later to become familiar, with the handle end resting against his shoulder for firm support. There is no evidence of a tool rest, although in turning the bottom of a bowl it would be more convenient to rest the tool on the tailstock, as he appears to be doing. The lathe bed,

11. This fact apparently led to one of the many errors about the early lathe in Singer, *et al., History of Technology*, Oxford, 1956, Vol. II, pp. 643-4.

12. Bibliothèque Nationale, MS Lat. 11,560, folio 84a.

the head and tailstocks, the treadle, the spring pole, and the drive cord wrapped around the workpiece, are all clearly shown.

By 1395 we have an illustration of a turner at work on his lathe (Fig. 12) from the *Zwölfbrüderbuch* of the Mendelschen Stiftung of Nürnberg. The intent of this series of drawings was after each brother's death to show him at work at his trade.[13] Here the action of the spring pole, cord, and treadle is quite clear. The turner is shown standing at his work, but in a position such that coordination between the pole drive and the operation of the tool would not be obtained by rocking his weight from one foot to the other. The cutting tools have short handles and are merely held in the hands, without any tool rest.

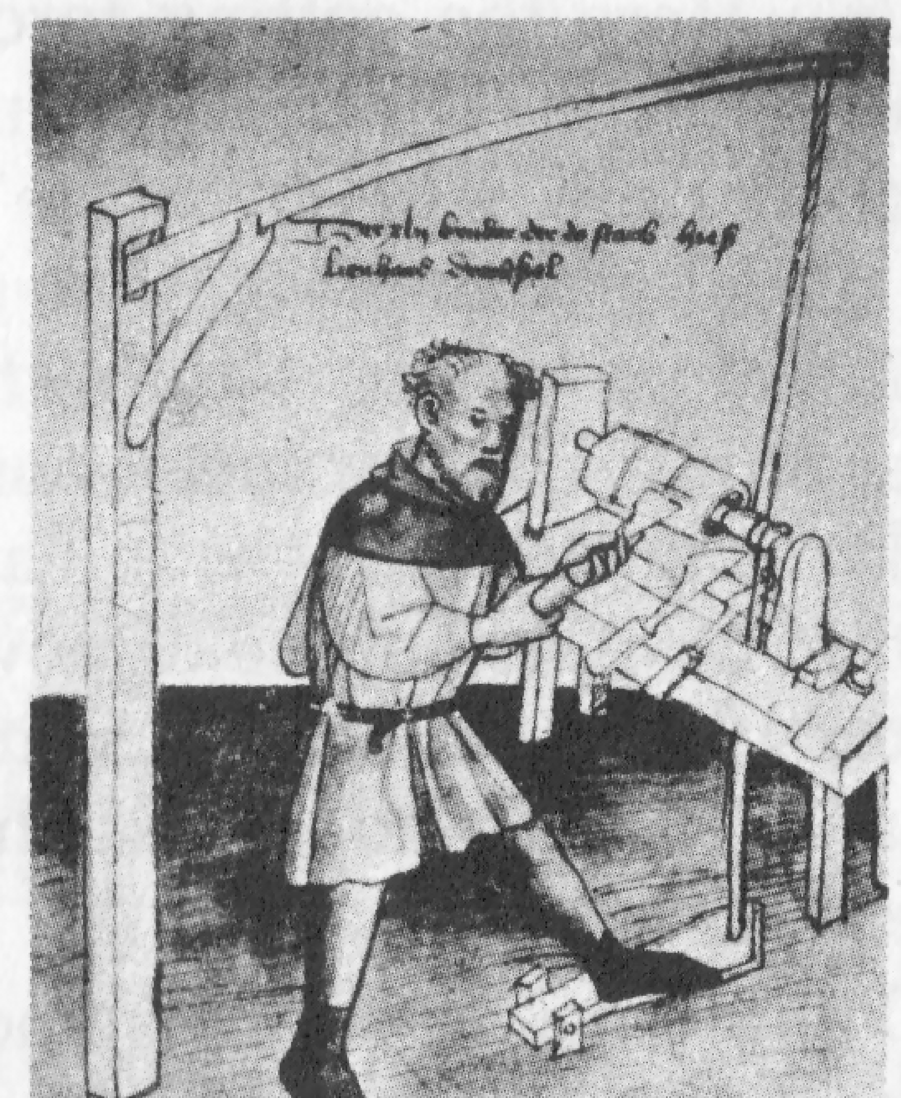


FIG. 12. THE POLE LATHE IN 1395. *(Mendelsches Brüderbuch)*

Our principal interest here is in the important progress made in the lathe bed and the head and tailstocks. All

13. It is in the Nürnberg Stadtbibliotek, folio 18v. Feldhaus devotes some lines to the 31st brother, the "Paternosterer," (maker of rosaries) but we can omit consideration of that drawing here, for his device is only a specialized horizontal drill press, bow driven, and not a lathe at all. The devices Feldhaus shows from the *Landaurschen Porträtbuch* are not lathes either.

are now made of heavy timbers and therefore are much more rigid. The tailstock is adjusted for workpieces of various lengths by a substantial wedge. The bed itself has now attained the basic form of two long heavy timbers, joined at each end by heavy pieces, and with the two heavy stocks mounted between the longitudinal timbers. The whole assembly is mounted on four substantial legs.

It is certain that all the elements of the spring-pole-and-treadle were in use by 1400.

The inconvenience of the alternating rotation of the workpiece, inherent in all the cord drives we have seen thus far, became a far more serious problem when the lathe was used to turn metals, even the non-ferrous metals. Here the cutting force required was such that the turner had all he could do merely to guide his cutting tool accurately, without at the same time coordinating it with an alternating rotation of the workpiece, to say nothing of providing with his foot the additional driving power required. For metal-turning the pole lathe would not do. The answer was to have continuous drive by an assistant or other source of power, such as a horse gin or a water wheel. Since such sources of power were already available, the question was—how to apply them to the drive of a lathe?

Continuous drive of a spindle by means of a cranked flywheel and cord is first shown in the drawing[14] of Figure 13. Here a large wheel has a crank, apparently driven by a treadle not shown, and is conveniently mounted below a bench so that a cord can give direct drive to a pulley carried on a spindle mounted between two bearings. This tool is intended only for light work not mounted between centers but held in a simple

14. Louvre Cabinet des Dessins, No. 2285, variously attributed, but clearly of the second half of the fifteenth century in Italy.

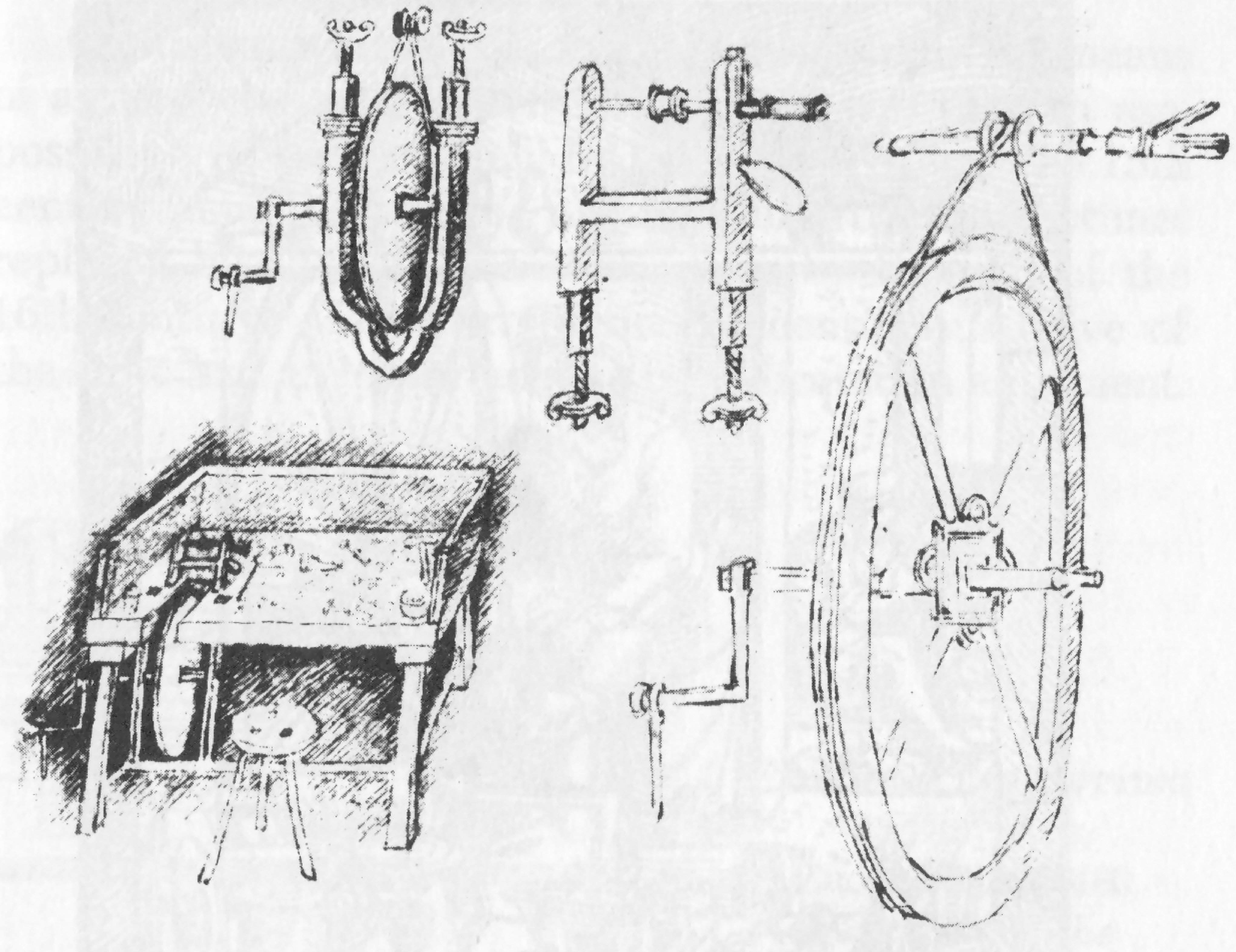


Fig. 13 Cranked Wheel and Cord Drive
Second Half, Fifteenth Century
(Louvre Cabinet des Dessins)

clamp chuck. A hand rest takes the place of a tool rest. Continuous drive of the spindle of a machine tool is an advance of the first importance, but this device may not be a lathe, for it could equally well be a gem engraver's tool. If so, an assistant turning a crank on a great wheel driving a cord to give continuous motion to the spindle was certainly in use by 1568, for we see it in Jost Amman.[15] (Fig. 14). Although the lathe itself is also shown here as largely schematic, we do see the long-handled tool braced under the armpit and surely with a tool rest hidden behind the work. There can be no doubt of the method of driving the workpiece. In the following year the records of the Nürnberg Coun-

15. Hans Sachs, *Alle Stände auf Erden,* Frankfort a. M., 1568, "Der Kandelgiesser."

FIG. 14. LATHE DRIVEN BY WHEEL AND CORD, 1568.
(Jost Amman)

cil[16] refer to the horse lathe of Hans Spaichel as clearly a new invention in demand by other turners, as was his treadle lathe of 1561. By 1590 we have a decision of the Council referring to a water-driven lathe. These are our first clear references to lathes driven by other than human muscles.

16. Theodor Hampe, *Nürnberge Ratsverlässe über Kunst und Künstler,* Leipzig, 1904, Vol. I, 3765ff, 3848ff, Vol. II, 7ff, 313-315, 366 382, 498, 538, 603, 622, 747, 750, 773, 776, 788, 792, 991ff, 1071, 1080, 1262, 1550, 1822.

Continuous drive of a metal-turning lathe by means of a hand crank, great wheel and cord was then in use, possibly by 1411, certainly by the second half of the 15th century, and the turner's assistant had been sometimes replaced by animals or water power by the end of the 16th century. The introduction of continuous drive of the lathe had an importance to be indicated in a moment.

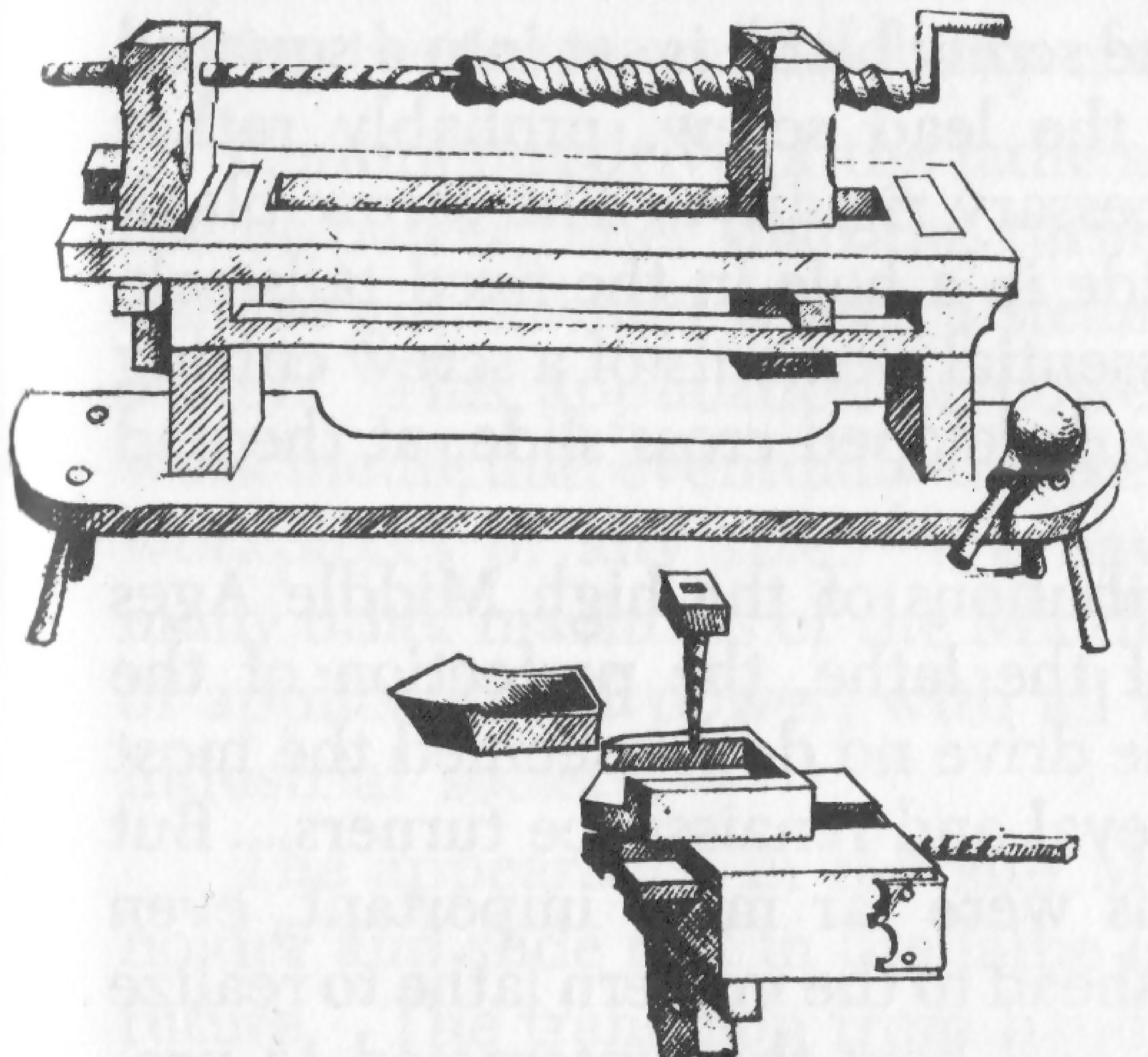


FIG. 15. SCREW-CUTTING LATHE WITH CROSS SLIDE, 1480.
(Mittelalterliche Hausbuch)

In the *Mittelalterliche Hausbuch,* of about 1480, we find a most important drawing,[17] for here for the first time control of the cutting tool is taken from the skilled hands of the turner and put into a mechanical device today called a "slide rest" (Fig. 15). It consists of the cutting tool itself, a special recess in which the tool is supported and prevented from turning, a holding screw, and we have all the elements of the modern tool holder. But there is much more. This tool holder is carried on a slide

17. Folio 53b. Three hundred years later a device almost identical with this is shown in Diderot's *Encyclopédie,* Planches: Vol. IX, "Taillanderie, Fabrique des Etaux," Pls. I and II.

providing for feed of the tool into the work by means of a screw mechanism looking very like modern cross-feed devices. And the whole is mounted on a slide rest which is fitted to a longitudinal guide way. This tool holder with its cross slide is intended to be wedged in place in the slot of the screw-cutting lathe shown above it. We then have a tool holder fixed in the longitudinal direction, and the workpiece moved in traverse by a lead screw passing through a movable threaded headstock and turned by a crank. The screw blank is set into a squared socket in the end of the lead screw, probably rather deeply to give the necessary rigidity. The screw blank can then rotate and slide in a hole in the fixed tailstock. We have here all the essential elements of a screw cutting lathe, including a fully developed cross slide, at the end of the 15th century!

Of the great contributions of the high Middle Ages to the development of the lathe, the perfection of the spring-pole-and-treadle drive no doubt seemed the most important to the medieval and renaissance turners. But the other contributions were far more important, even though one must look ahead to the modern lathe to realize their great signficance and how they interacted to produce the basic elements and characteristics of the lathe of today.

The stronger construction of the lathe bed and its stocks laid the foundation for turning much heavier work and for turning metal. Taken together with mechanical holding and control of the cutting tool, it is the first step in the direction of precision working on the lathe—a development that we shall see come to a climax with Maudslay.

Continuous drive was not merely a convenience and improvement in speed and accuracy of turning. Without it a tool holder controlled by a mechanism, either hand or automatic, is not feasible, because it is mechanically too

difficult to provide the coordination of the cutting motion and the alternating rotation heretofore based on the hand skill of the turner.

Other new possibilities of development were created by continuous drive. Now, with the help of a large driving wheel, the speed of rotation of the workpiece could be substantially increased. More important, by the use of suitable pulleys the speed and the mechanical advantage could be varied to suit the turner's needs, thus enlarging the scope and flexibility of this basic machine tool.

Continuous drive of the lathe also adapts easily to the use of power other than the turner's—a "dull Irishman," a horse gin, a water wheel, a steam engine, or an electric motor. This application of power makes it possible to work metal, and eventually to take heavy cuts and to turn workpieces of any size. We have here then, as in so many other machines of the Middle Ages, the beginnings of application of power, with all that that means for an industrial society.

The appearance in the late Middle Ages of the tool holder and slide rest in the lathe is also pregnant for the future. The transition from hand control of the cutting tool to mechanical control is of first importance. It of course provides ease of working as well as greater precision. But more important, power drive of the workpiece was to lead, early in the 18th century, to power drive of the tool relative to the work being turned. Both are crucial for the metal-cutting lathe.

When the ornamental turners later provided means for automatically controlled motion of the tool device, highly complex forms were possible, as we shall see. Even for the industrial lathe, the old hand skill of the turner is no longer needed. Given a blue print, any technical school graduate could turn out the Uffing vase in a short time today. We see here the beginnings of

"building the skill into the machine" which was to lead to modern, fully automatic lathes.

It should be noted, however, that no one of these important first steps would have been significant in itself alone. All required the others, as well as still further elements which we shall examine. We can now understand from their very beginnings in the Middle Ages, the interaction of many elements which made the modern lathe possible.

This early period also experienced some of the social effects which in later times new tools were to produce, or at least similar reactions, for the Council of Nürnberg on several occasions from 1559 to 1591 forbade inventors to use improved and power-driven lathes, had the machines destroyed, or put the inventors in jail for their flagrant violations of repeated orders to stay within guild regulations.[18]

LEONARDO DA VINCI AND HIS FOLLOWERS

Although Leonardo da Vinci's specific contributions to actual machine tools, including the lathe, are difficult to establish, we can see in his drawings of tools much of the same originality he exhibited in his other technical work.

We find in the *Codice Atlantico* the first sketch of another important drive of the lathe—a treadle acting on a crankshaft, with a flywheel.[19] (Fig. 16). The lathe itself is shown only schematically. Although the tailstock is fixed, a tailstock spindle adjustable by a hand crank is clearly shown, the first evidence we have for the use of this method of adjustment in holding workpieces of different lengths between centers.

The driving crankshaft is formed directly on the lathe spindle, which now has two distinct bearings, as well as

18. Hampe, *loc. cit.*
19. *Codice Atlantico*, fol. 381Rb.

FIG. 16. LATHE WITH SPINDLE DRIVE, LEONARDO DA VINCI, ABOUT 1500. *(Codice Atlantico)*

an additional bearing to support the outer end of the flywheel shaft. The treadle is connected to the crank pin only by a cord, not a connecting rod. This type of drive is more important than it may at first seem, for it is the first appearance in the center lathe of a head spindle mounted between *two* bearings and driven *in between them.* In the drives that we have considered thus far, the workpiece has a cord wrapped directly around it, or at least around the mandrel on which it is mounted. In the modern center lathe the workpiece is also commonly supported between centers. One, called the "dead" center, is carried in an adjustable tailstock spindle which permits taking work of different lengths, as well as a fine adjustment of the support of the work on the centers. The other center, called the "live" center, is carried on a spindle rotating in two bearings mounted in the fixed headstock. The drive, or rotary motion, of the spindle is applied between these two bearings. This arrangement makes possible rigid support of the work under heavy cutting loads. Although the drive is almost never a crank, as with Leonardo, this sketch shows for

the first time[20] these two most important elements in the drive of the modern lathe.

While Leonardo's actual crank drive was abortive, the importance of spindle drive is not to be underestimated. It takes a major step toward accuracy by providing rigid support while driving either a wooden workpiece on center points or metallic work on centers by use of the lathe dog. It also leads toward a cone pulley mounted on the spindle to give variable speed drive. With a driving spindle mounted in two bearings we also have the basis for use of a face plate, which permits turning discs and non-circular work otherwise impossible to turn. With a face plate we can bore and tap on the end of the workpiece. Spindle drive is also essential to the use of a chuck,[21] to make possible the turret lathe and automatic feed of stock through a hollow spindle—both important elements of high production rates in modern turning.

It is then evident that by the beginning of the 16th century we have continuous drive, heavier construction of bed and stocks, a mechanical tool holder and carriage, and spindle drive—all important elements of the modern lathe.

We do not know if Leonardo's sketch was of his own invention or of a device already in use. However, by 1561 Hans Spaichel had newly invented a lathe in Nürnberg which sounds very much like this lathe of Leonardo's. It is probable that Spaichel had even taken the next step in the drive—to use the flywheel itself as the crank, and to use a cord to transfer the motion of the wheel to a continuous spindle drive. The records of the Council refer only to "the wheel of the lathe," "treadle," "bushings

20. It is possible that these elements were in the Glastonbury method (3), but we cannot be sure.

21. This development will be treated in detail in a later monograph on the *History of Jigs, Fixtures, Arbors, and Chucks.*

and shafts." But these officials were not interested in the technical details of Spaichel's lathe, only in the fact that it threatened the then common lathe and that, contrary to guild regulations, Spaichel was selling such lathes to other turners, particularly to the goldsmiths. So we cannot be sure just what sort of lathe Spaichel had, except that it was enough of an improvement for a customer to make it worth the inventor's while to defy the authorities, and that it was a substantial variation from the accepted pole lathe of the time.

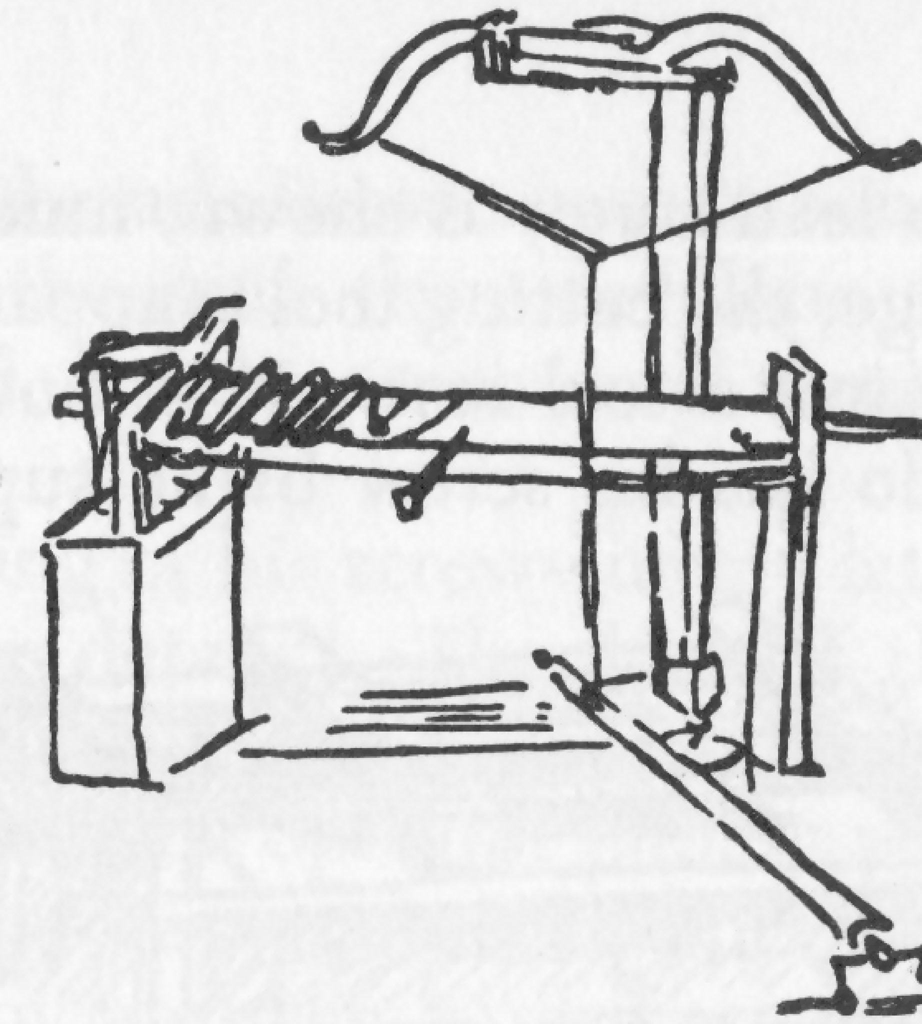


FIG. 17. SCREW-CUTTING LATHE, LEONARDO DA VINCI, ABOUT 1500. *(Codice Atlantico)*

Leonardo was also interested in the improvement of the pole lathe,[22] for in Figure 17 we see a bow of wood or metal replacing the spring pole, in order to get a greater working force. The driving cord (probably of catgut, fine hemp or linen) was secured in the middle of the bow cord. Although lathe drives of this type are seen later (Figs. 20 and 28), they did not supplant the pole lathe by any means, any more than did the crank and flywheel lathe.

Before we leave this bow lathe of Leonardo's we must note a feature not very clear in his sketch. Leonardo and many of the engineers of the "Italian School" show frequent use of the screw in all kinds of technical devices, both large and small. The method of cutting these screws by hand was clearly a handicap. Leonardo is here trying to develop a means of cutting such screws on the lathe.

22. *Codice Atlantico,* folio 14Ra.

No lead screw is shown, much less a tool holder or carriage; the cutting tool is apparently held only in the hand against a tool rest. It is, however, probable that Leonardo has his screw blank supported on spindles free to slide in bearings at the head and tailstock. The part of the screw thread already cut, presumably by hand, is then used as a lead screw to cut the rest. This is accomplished by a framework supporting a vertical pin which engages the thread already cut. As the work rotated it would then slide back and forth to form the screw thread. If this interpretation is correct, Leonardo has introduced the principle of the traversing spindle so common in the ornamental turning lathes of the 18th century.

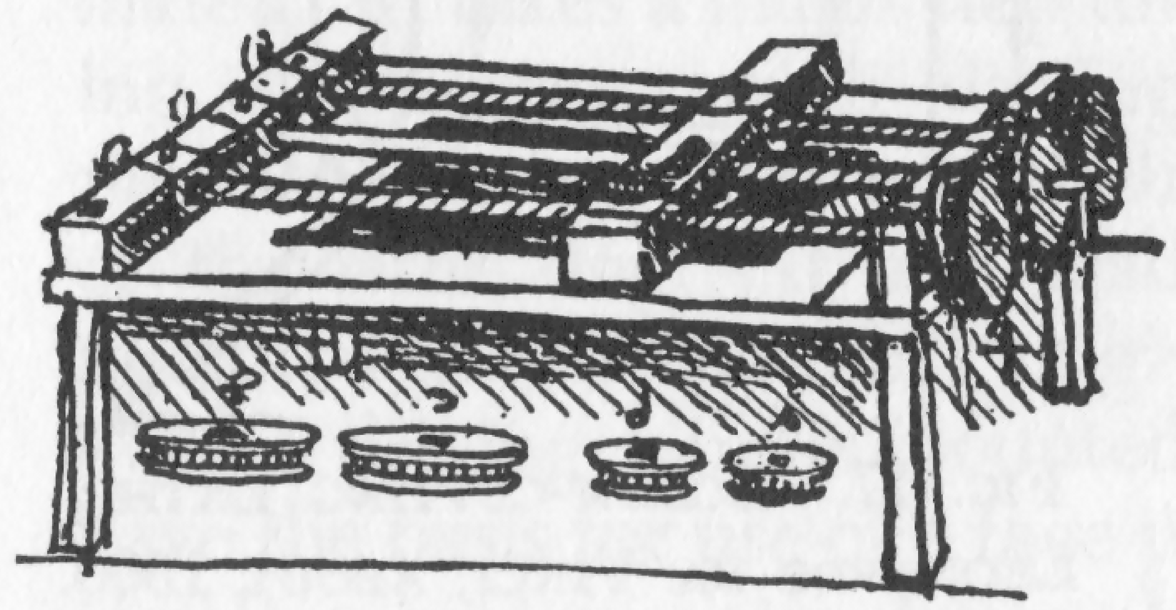


FIG. 18. LEONARDO'S SCREW-CUTTING MACHINE, ABOUT 1500. *(Inst. Fr. MS. B)*

We should also note Leonardo's screw-cutting machine (Fig. 18).[23] Although this device is too specialized to call it a lathe, it does have a carriage carrying a cutting tool and driven by a lead screw. In this case there are two lead screws, since they act as guides for the carriage. We must also note that Leonardo here shows the first use of change gears in screw cutting to give threads of various pitches. It therefore is a most important advance over the screw cutting lathe of 1480 (Fig. 15).

After Leonardo, interest in the lathe centers less on the means of drive than on means of control of the cutting tool relative to the workpiece. In this movement Jacques Besson, Leonardo's successor as engineer to the French court, is the transition figure, for from Leonardo's industrial lathe for cutting screw threads Besson goes to a most important screw-cutting lathe and then develops the foundations laid by Leonardo for the ornamental turning lathe.

23. *Inst. Fr. MS. B,* fol. 70V.

Besson shows us a drawing of his screw-cutting lathe (Fig. 19) and describes it in detail.[24] The drive of this lathe has an auxiliary shaft mounted above, which is given an alternating motion by the operator pulling with his right hand on a cord against a counterweight. The work is alternately rotated by a cord wrapped around it and leading from a drum on the auxiliary shaft to a counterweight. In its entire drive, Besson's lathe represents a definite retrogression, although the bed structure, head and tailstocks do have the solid, rigid construction of a century earlier. We have a tool holder, but without the cross feed screw we saw in 1480. Instead, the cross feed is by means of counterweights acting on each end of a bar carrying a tool holder slidable along it. This bar also carries a pedal by which the operator can disengage the tool on the return alternation of the workpiece. This method of controlling the tool in cross feed is another retrogression.

In the longitudinal feed of the tool, however, we have something new and important. The tool holder is moved by a bar sliding through a hole in the center stock. This bar carries on its other end a cage which slides through two auxiliary stocks. All three stocks can be fixed in any convenient location by wedges to prevent them from sliding between the lathe bed bars. The cage has fixed in it a nut which engages a screw, also alternately rotated by a counterweight from another drum on the auxiliary shaft. In this way a lead screw, for that is what Besson has here, guides the cutting tool in coordination with the drive. There would, of course, be some slippage in all

24. Jacques Besson, *Theatrum Machinarum,* Lyon, 1578, Prop. IX and Plate IX.

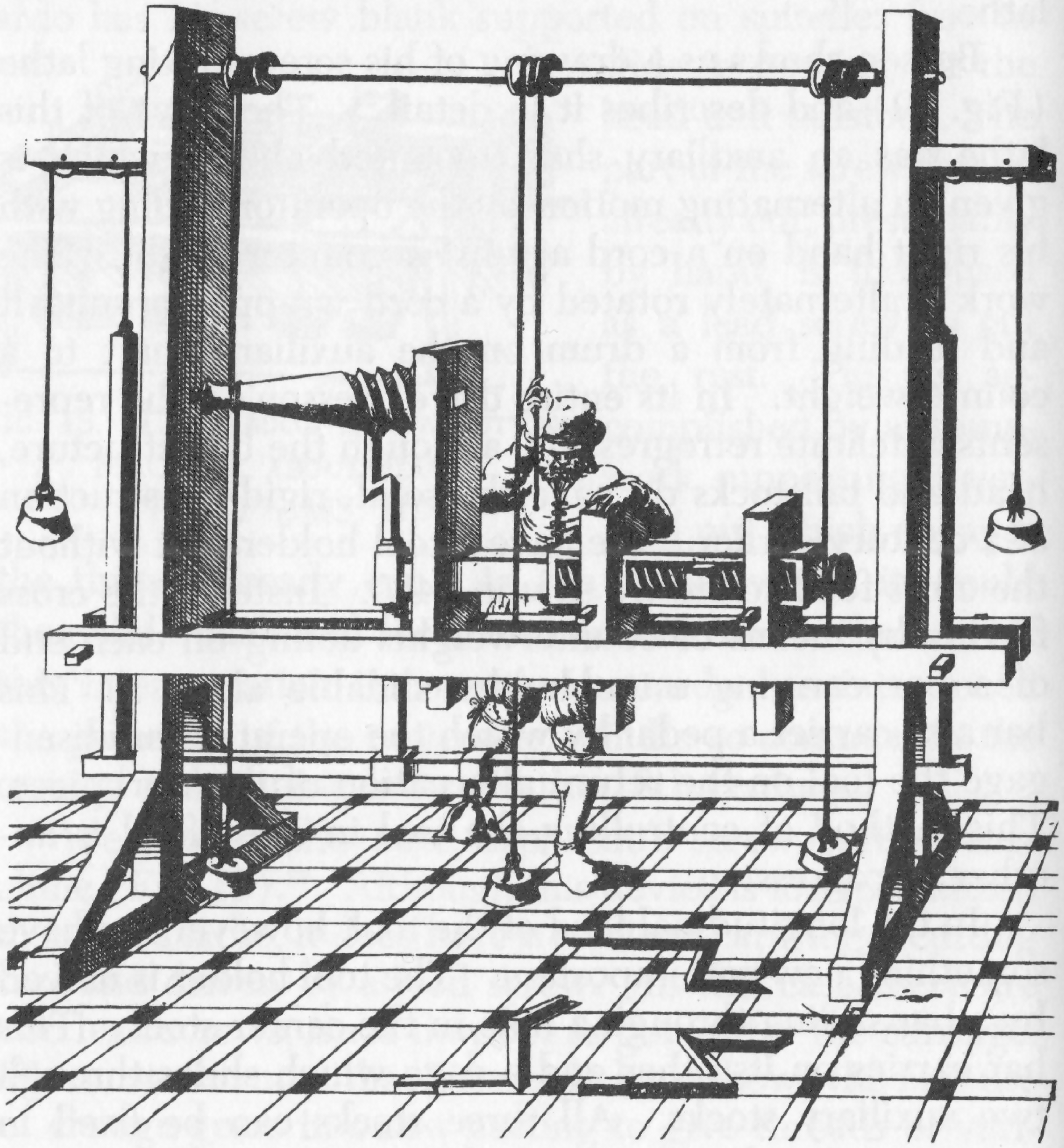


FIG. 19. BESSON'S SCREW-CUTTING LATHE, 1578.
(Besson)

these cords, so that the accuracy of reproduction of the lead screw is open to question; but since Besson frankly aims only at ornamental work, this defect can be ignored. Although Besson does not note the fact, proper choice of the drum diameters on the auxiliary shaft would permit threads of any desired pitch to be cut from the one lead

screw, and crossing of cords would give a left-hand thread if desired. The cutting tools scattered on the floor are of interest, and one should also note that a non-cylindrical form, a conical screw, is being turned here.

This machine is so cumbersome and complex that one can hardly believe that it was ever actually in use. It does, however, mark the first use of a lead screw and nut for longitudinal feed of a lathe tool, another important element of the modern machine tool. In theory the operator of this lathe need only pull and release the cord and coordinate the pedal motion with this driving action; it is therefore the first semi-automatic lathe, with the skill built into the machine tool.

With Leonardo and Besson the industrial lathe had made important progress in the drive of the workpiece and in the longitudinal feed of the tool. We must now look briefly at an interesting by-path in the development of the lathe—ornamental turning.

THE ORNAMENTAL TURNERS – COMPLEX DEVICES

With Jacques Besson we come to a fork in the path of the development of the lathe. His screw-cutting lathe, which we have already examined, is on the way to the industrial lathe, but he describes two other lathes which lead to many features of the ornamental turning lathe. This complex machine tool began as an industrial machine intended to turn various ornamental objects of every day use, such as vases, the baroque balusters for stairs, and so forth; it ended as a hobbyist device designed to turn out "curios" and having its one real importance in that it led de la Condamine to investigate its geometry with some interesting results.[25] Most of these hobbyists came of the top level of society, since these lathes were

25. Charles Marie de la Condamine, "Description et usage d'une machine qui unite les mouvements du tour," p. 216, and "Examen de la nature des courbes qui peuvent se tracer par les mouvements du tour," p. 295, in *Histoire de l'Académie des Sciences*, Paris, 1734.

beautiful and costly examples of craftsmanship. The craft of turning thus doubtless received some social recognition, but its effects are difficult to establish, except that court engineers such as Besson and de Caus devoted their attention to such devices. In any case, the intellectual and social world to which the ornamental turning lathe owed its origin went under in the French Revolution. What followed—the creation of the industrial metal-cutting lathe—came from another way of thought and reached its full flowering in England. In the 17th and early 18th centuries the technical demands were not such as to bring about a rapid development of the industrial lathe.

This by-path of ornamental turning is fascinating to explore,[26] but we must here confine ourselves only to those aspects which influenced the development of the industrial lathe. One of these was the use of templets and cams to obtain intricate motions. In this way we may control the motion of the tool, either in longitudinal or in cross feed, or we may control the motion of the workpiece either along or at an angle to its axis or revolution. As we shall see, the control of the workpiece was of great importance for the ornamental turning lathe, but control of the tool in ornamental work led to mechanical control of the tool to produce the less intricate but more precise forms of the industrial lathe.

In Besson[27] we see (Fig. 20) the use of both cams and templets to get intricate forms. Here an elliptical cross section of the work is obtained by circular cams mounted on an extension of the lathe spindle so as to permit being set at any desired angle and to bear on a tool guide bar to give the tool the necessary oscillation.

26. S. G. Abell, J. Leggat, and W. G. Ogden, Jr., eds., *Bibliography of the Art of Turning* (Privately printed for the Society of Ornamental Turners), London, 1956.

27. Besson, *loc. cit.*, Prop. VIII and Plate VIII.

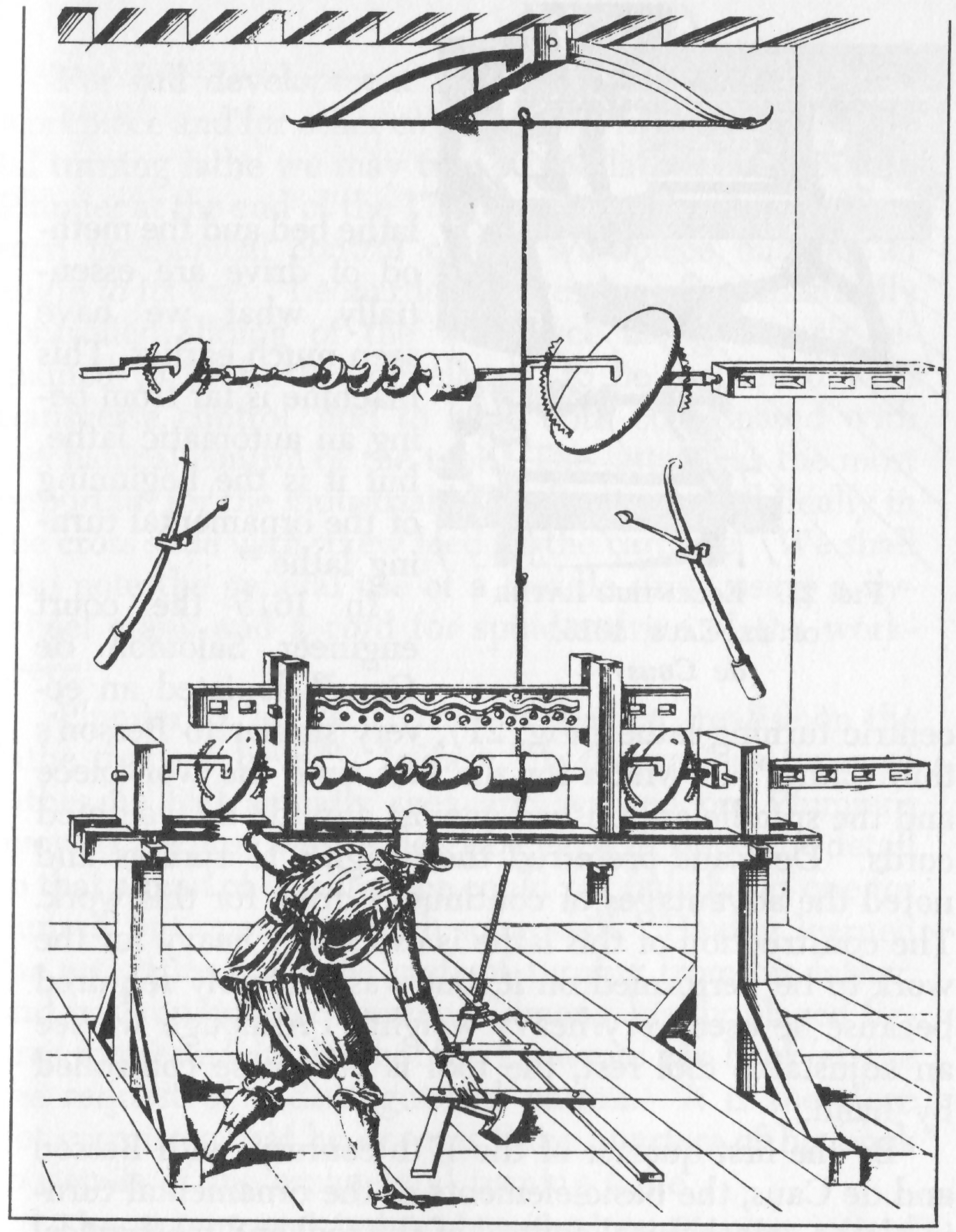


FIG. 20. BESSON'S ORNAMENTAL TURNING LATHE, 1578. *(Besson)*

Non-circular cams could be used to produce more intricate cross sections. The tool guide bar had cut in it a templet slot to give the desired profile to the workpiece, and could slide up and down between guides. The forked hand tools used for this work are shown on the wall and have one arm carrying the cutting point and the other designed to slide in the templet slot. Considerable hand skill must have been required to manipulate these tools, but the accuracy desired was not very great. The

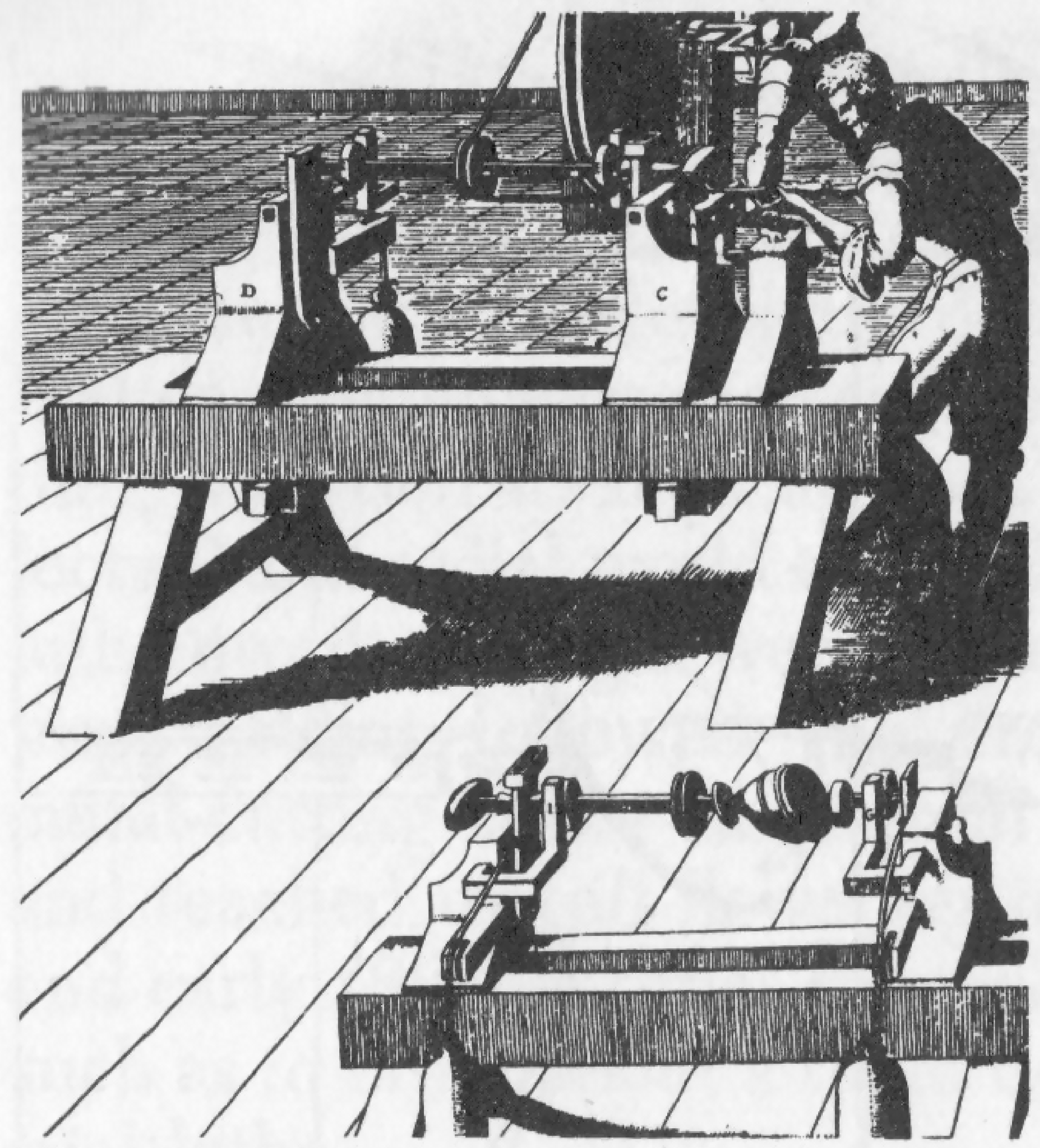


FIG. 21. ECCENTRIC LATHE OF DE CAUS, 1615. *(de Caus)*

lathe bed and the method of drive are essentially what we have seen much earlier. This machine is far from being an automatic lathe, but it is the beginning of the ornamental turning lathe.[28]

In 1615 the court engineer Salomon de Caus[29] depicted an eccentric turning lathe (Fig. 21), very similar to Besson's third lathe,[30] in which for the first time the workpiece and the spindle are pushed against a guide by weighted cords. De Caus preferred the weights to springs and noted the advantages of continuous drive for this work. The construction of this lathe is especially heavy for the work to be performed on it, but was probably required because he used very heavy weights. Although we see an adjustable tool rest, the tool is otherwise controlled by hand.

By the first quarter of the 17th century, with Besson and de Caus, the basic elements of the ornamental turning lathe—mechanical control of the tool and mechanical control of the workpiece, to produce eccentric forms—had been developed, although some hand skill was still required. These two elements had not yet, however, been combined in a single lathe. Nevertheless, the lathes of both men were still designed to serve industrial purposes.

28. The author has been unable to find evidence to support the statements by Chasles, Reuleaux, and others that Leonardo da Vinci had the ellipse chuck mechanism.

29. Salomon de Caus, *Les Raisons des Forces Mouvantes,* Frankfurt, 1615, Bk. I, Prob. XXI.

30. *Besson, loc. cit.,* Prop. VII and Plate VII.

For full development of mechanical control of the workpiece and for other contributions from the ornamental turning lathe we may turn to the lathes described in Plumier at the end of the 17th century. Thus far we have seen mechanical control of the workpiece only at an angle to its axis. Leonardo's suggestion of mechanically controlled sliding of the workpiece along its axis remained to be further developed, to be combined with transverse control, and to have both coordinated with mechanical control of the tool. The latter was the most important for the industrial lathe, for it resulted finally in the cross slide with screw feed on the carriage. We shall also note the general use of a treadle drive using a flywheel crank and a cord for spindle drive of the workpiece.

Plumier's *L'art du Tourner* is the first treatise on the lathe that we have.[31] In fact, for the various types of lathes he had actually seen and worked on, Plumier's avowed purpose was to describe each in sufficient detail so that a man of intelligence could not only build one for himself but operate it with some skill. Having learned the art, rather than the craft of turning from his father, and with a wide acquaintance among highly placed figures interested in this hobby, he wrote his book at the the request of a distinguished patron. It is therefore not surprising that he devotes three quarters of his book to details of the ornamental turning lathe.

The ornamental lathes described in Plumier are of much less interest to us here than those of his predecessors. His are confined largely to lathes producing their designs by cams and other devices sliding the lathe spindle longitudinally along its axis as well as at right

31. Charles Plumier, *L'Art du Tourner,* Lyon, 1701. There is reason to believe that Plumier had completed this work as early as 1689. It therefore probably antedates Joseph Moxon's less detailed account, Part III of his *Mechanik Exercises,* London, 1693.

angles to it. (Fig. 22). Means of mechanically controlling the tool are also shown, but this is always done by cams working against weights and springs, not by screws or other means significant for the industrial lathe. For ornamental turning these devices permit much more complex turning than anything we have seen before.

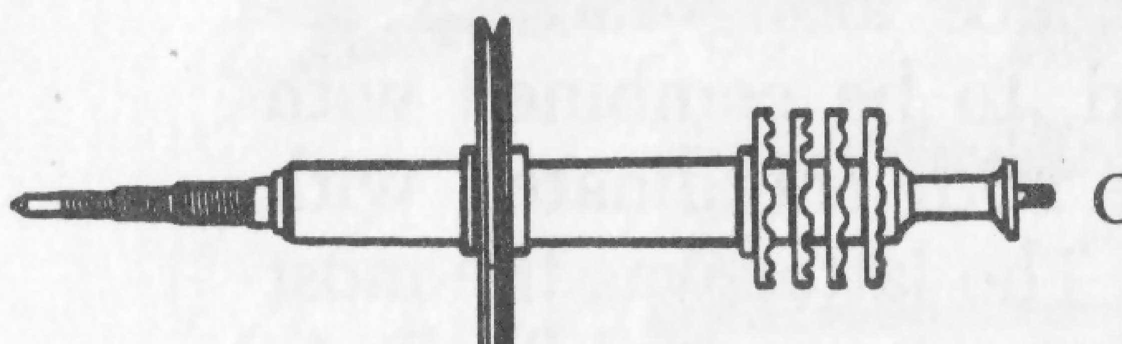


FIG. 22. SLIDING SPINDLE OF THE ORNAMENTAL TURNING LATHE, 1701. *(Plumier)*

The principal feature of these hobbyist's lathes of interest in the development of the industrial lathe is the means provided for screw cutting. This method of producing a screw thread was to use one of several screws laboriously cut on a lathe spindle which was then mounted so as to slide axially in its bearings. Provision for engaging the desired master thread was made by means of a set of corresponding half nuts on keys which could be

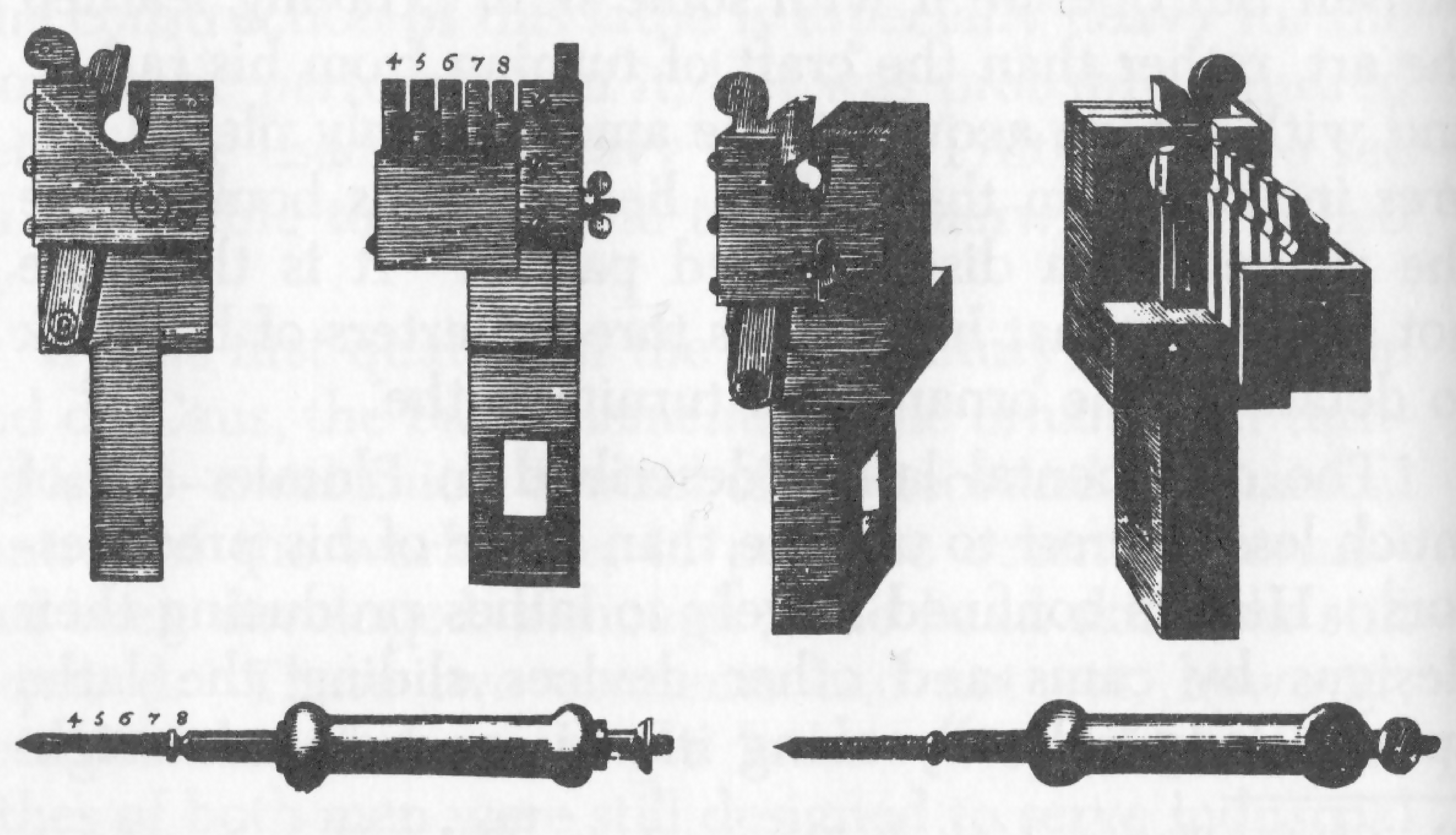


FIG. 23. SCREW CUTTING ON THE SLIDING SPINDLE, 1701. *(Plumier)*

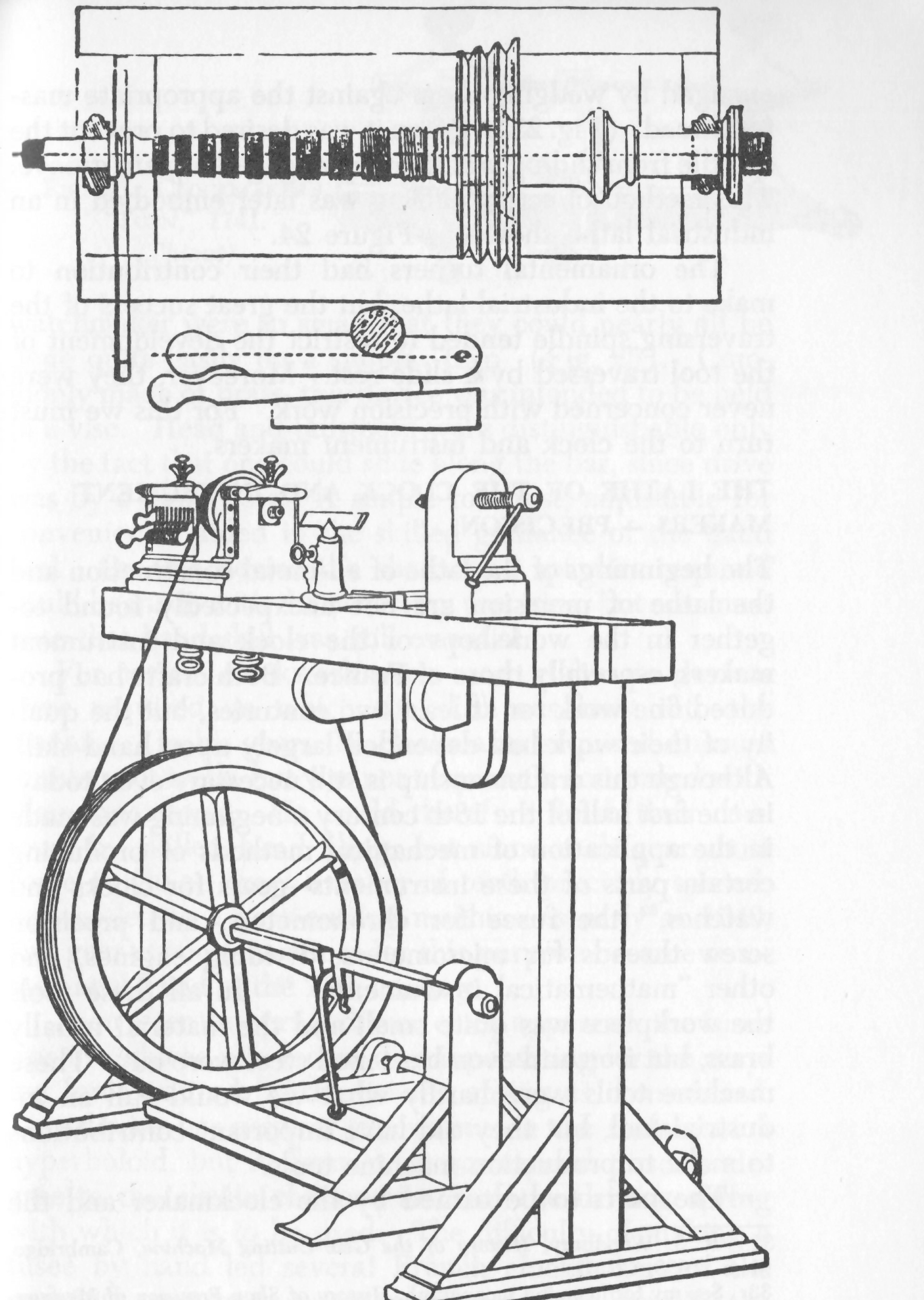


FIG. 24. INDUSTRIAL SCREW-CUTTING LATHE OF 1785. *(Holtzapffel)*

engaged by wedging them against the appropriate master thread. (Fig. 23). When it was desired to prevent the spindle from sliding, another key engaged a plain groove. This method of screw cutting was later embodied in an industrial lathe shown in Figure 24.

The ornamental turners had their contribution to make to the industrial lathe, but the great success of the traversing spindle tended to restrict the development of the tool traversed by a slide rest. Moreover, they were never concerned with precision work. For this we must turn to the clock and instrument makers.

THE LATHE OF THE CLOCK AND INSTRUMENT MAKERS – PRECISION

The beginnings of the lathe of all-metal construction and the lathe of precision are not unexpectedly found together in the workshops of the clock and instrument makers, especially those of France. Both crafts had produced fine work for at least two centuries, but the quality of their work had depended largely upon hand skill. Although this craftsmanship is still necessary even today, in the first half of the 18th century a beginning was made in the application of mechanical methods of producing certain parts of these instruments—gears for clocks and watches,[32] the fusee for chronometers, and precision screw threads for micrometers, dividing engines, and other "mathematical instruments."[33] In all these tools the workpiece was quite small and the material usually brass, but iron and even hardened steel were cut. These machine tools were hardly what we would call an industrial tool, but they did have important contributions to make to production machine tools.

The parts to be turned by the clockmaker and the

32. R. S. Woodbury, *History of the Gear-Cutting Machine*, Cambridge, Mass., 1958, Ch. II.

33. See my forthcoming monograph, *History of Shop Precision of Measurement and Interchangeable Parts.*

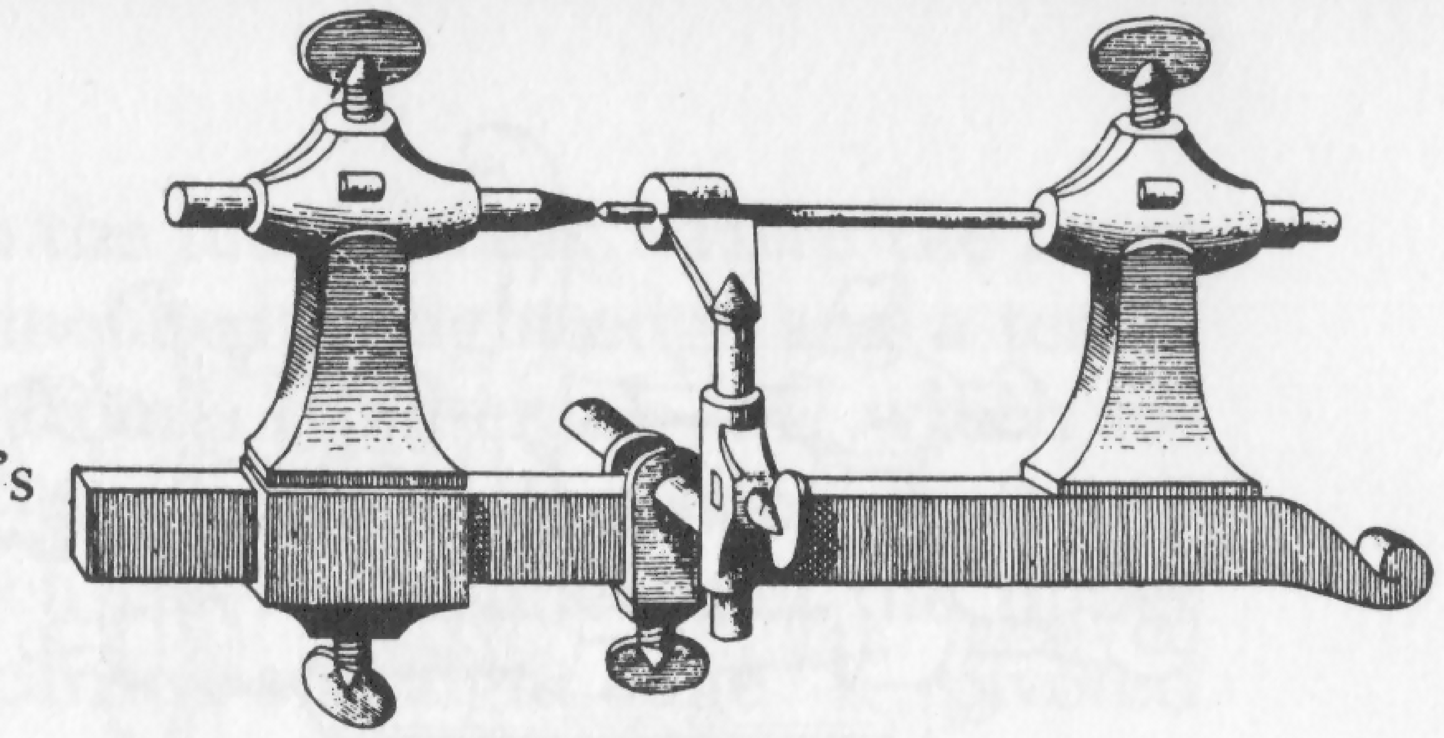


FIG. 25. CLOCKMAKER'S "TURN," 1741. *(Thiout)*

watchmaker were so small that they could nearly all be done quite easily on a simple "turn" (Fig. 25). Commonly made of brass, this device was intended to be held in a vise. Head and tailstocks were distinguishable only by the fact that one could slide along the bar, since drive was by a hand bow. A simple tool rest, adjustable for convenience, aided in the skilled guidance of the hand tool. On this device the shafts and spindles required could be made with the necessary precision, but one must note that hand skill was still essential.

For certain clockwork parts more elaborate devices were required, in which the skill was built into the machine. In his gears the clockmaker required unusual numbers of teeth, but was not very much concerned with their exact form. He could therefore finish their contours by skilled hand filing; but since each gear must come out to an exact number of teeth precisely spaced, he was led to a gear-cutting machine as early as 1540, and gear-cutting machines for this purpose became common at the end of the 17th century.

Soon after the spring driven clock appeared, the fusee was introduced as a means of compensating for the varying force exerted by the driving spring as it unwound. This device has a spiral groove cut on the surface of a hyperboloid, but its form must correspond to some degree to the elastic characteristics of the driving spring with which it is to be used. The difficulty of making a fusee by hand led several French clockmakers of the mid-18th century to invent machine tools to simplify the operation.

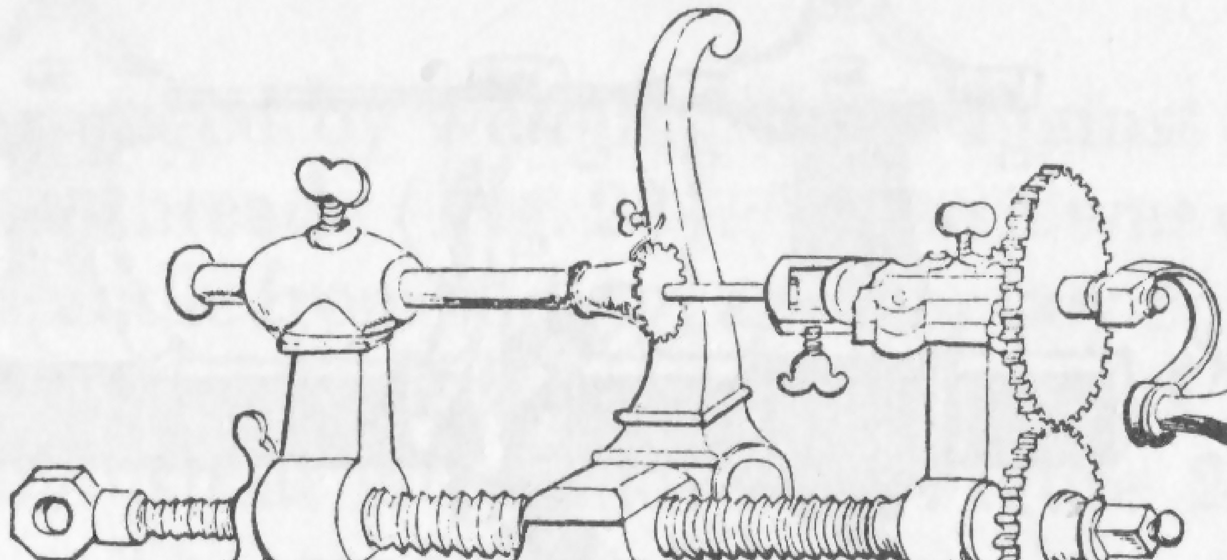


FIG. 26. EARLY FUSEE ENGINE, 1741. *(Thiout)*

A simple fusee engine is shown in Figure 26 from Thiout.[34] Here we see a machine entirely of metal, with a lead screw and change gears controlling the cutting tool for the spiral thread. The in-feed is, however, determined by hand to follow the hyperbolic profile of the fusee. A more complex machine,[35] fully automatic, is shown in Figure 27. This was intended to cut the exact

34. Antoine Thiout, *Traité de l'horlogerie*, Paris, 1741, Vol. I, Plate XXVII, Fig. 1.

35. Ferdinand Berthoud, *Essai sur l'horlogerie*, Paris, 1763, Vol. I, pp. 150 ff. and Plate XVII, Fig. 1. See what is probably its ancestor in Thiout, *loc. cit.*, pp. 69-72 and Plate 27, Fig. 2.

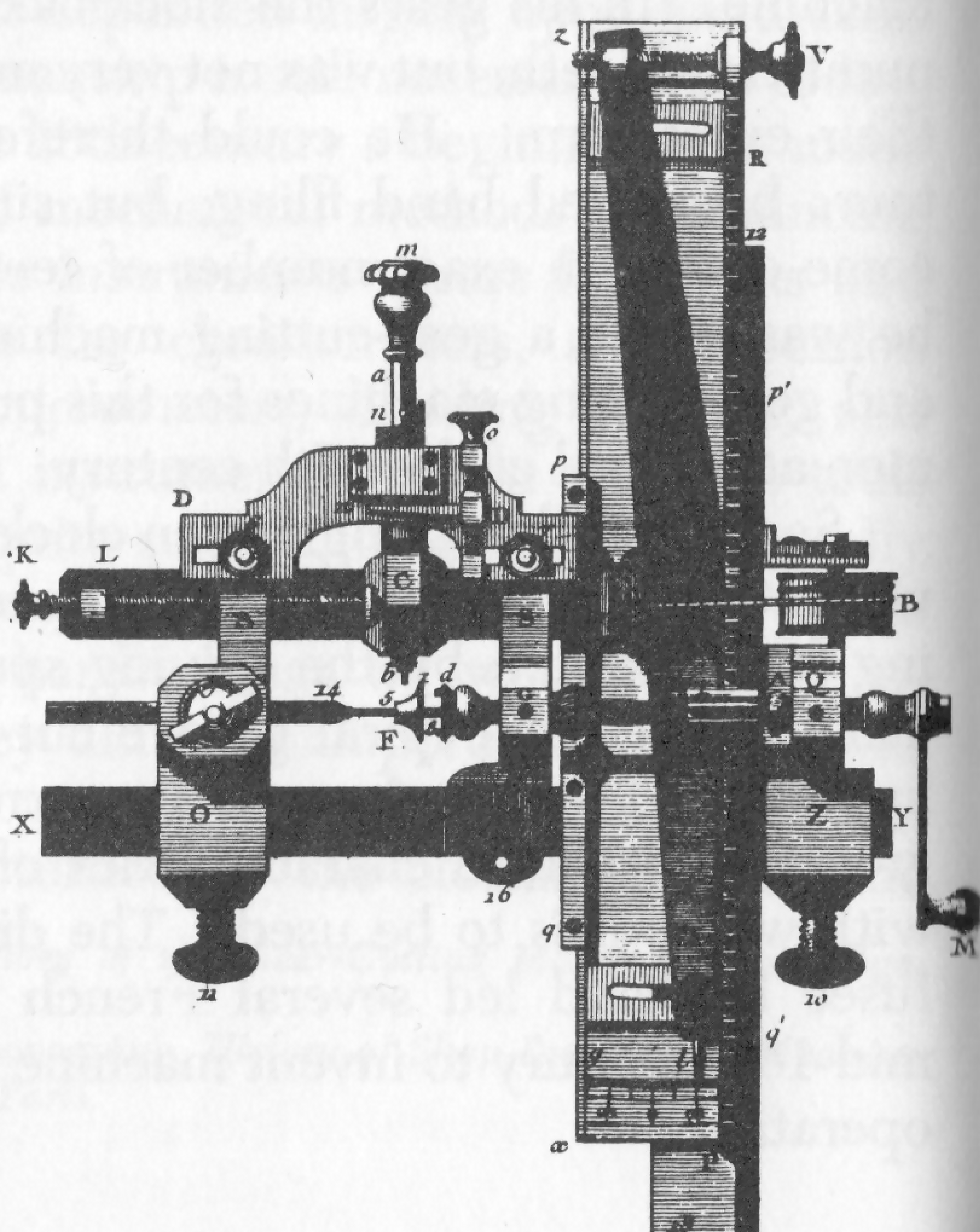


FIG. 27. FUSEE ENGINE, 1763. *(Berthoud)*

form of the fusee from the rough blank. Here the fusee is cut by means of an inclined straight edge and a templet. Power is derived from a hand crank "M" which rotates the workpiece. A pinion on the same shaft engages a rack "R" which carries a slide. On the upper surface of the slide is carried a straight edge "I", pivoted and arranged to be set at the inclination desired by means of adjusting screws, division marks, and clamping screws. Another slide "D" carries the tool and has its end bearing against the inclined straight edge "I". This slide and the tool are drawn to the left by means of a light chain around the barrel "B", which is tending to rotate by means of a spring coiled inside it. Adjustments are provided for setting the initial position of the tool in traverse and in cross feed. The operator then turns the crank "M" with one hand, and the other holds the pin "a" in the toolholder handle against the templet "n" which forms the hyperboloid.

Here we see a lathe, specialized to be sure, but *all metal* and cutting a *precision* metal part with a tool controlled in both traverse and cross feed by adjustable, automatic mechanisms.

The clockmakers also required a number of screw threads in their work, all of which had to be made with some precision. In 1701 Plumier showed a clockmaker's lathe for screw cutting using a sliding spindle with a set of master threads (Fig. 28). Thiout also constructed a machine for this purpose (Fig. 29).[36] In his device the motion of the carriage is controlled by an adjustable linkage operated by a lead screw integral with the headstock spindle, an interesting variation from the use of change gears. This device is also entirely of metal and intended to give precision.

36. This example of his work is to be found in the Musée du Conservatoire National des Arts et Métiers, Paris, No. 1234. One slightly different can be seen in the Science Museum, London. (Inv. 1937-185)

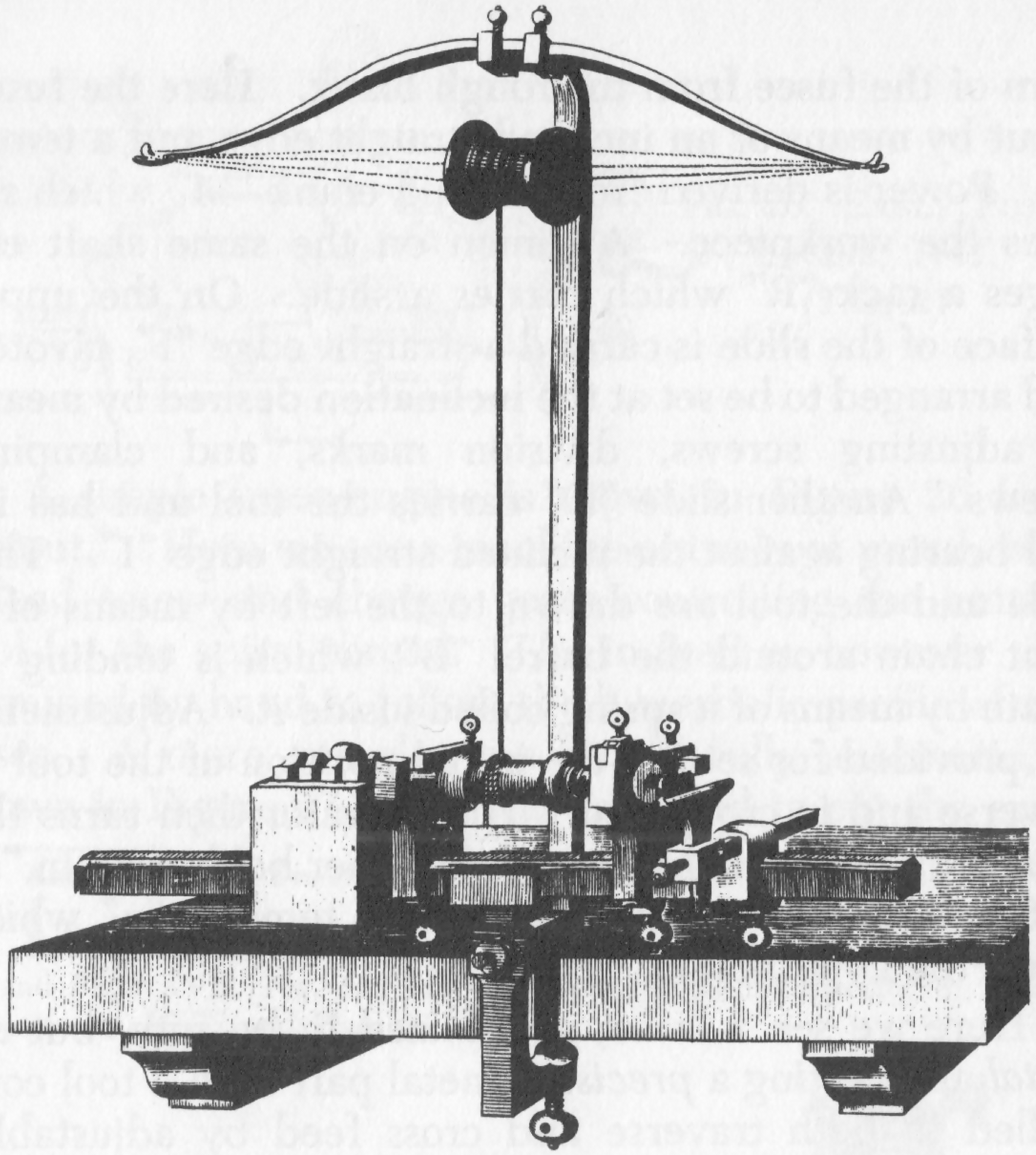


Fig. 28. Plumier's Screw-cutting Lathe for a Watchmaker, 1701.
(Plumier)

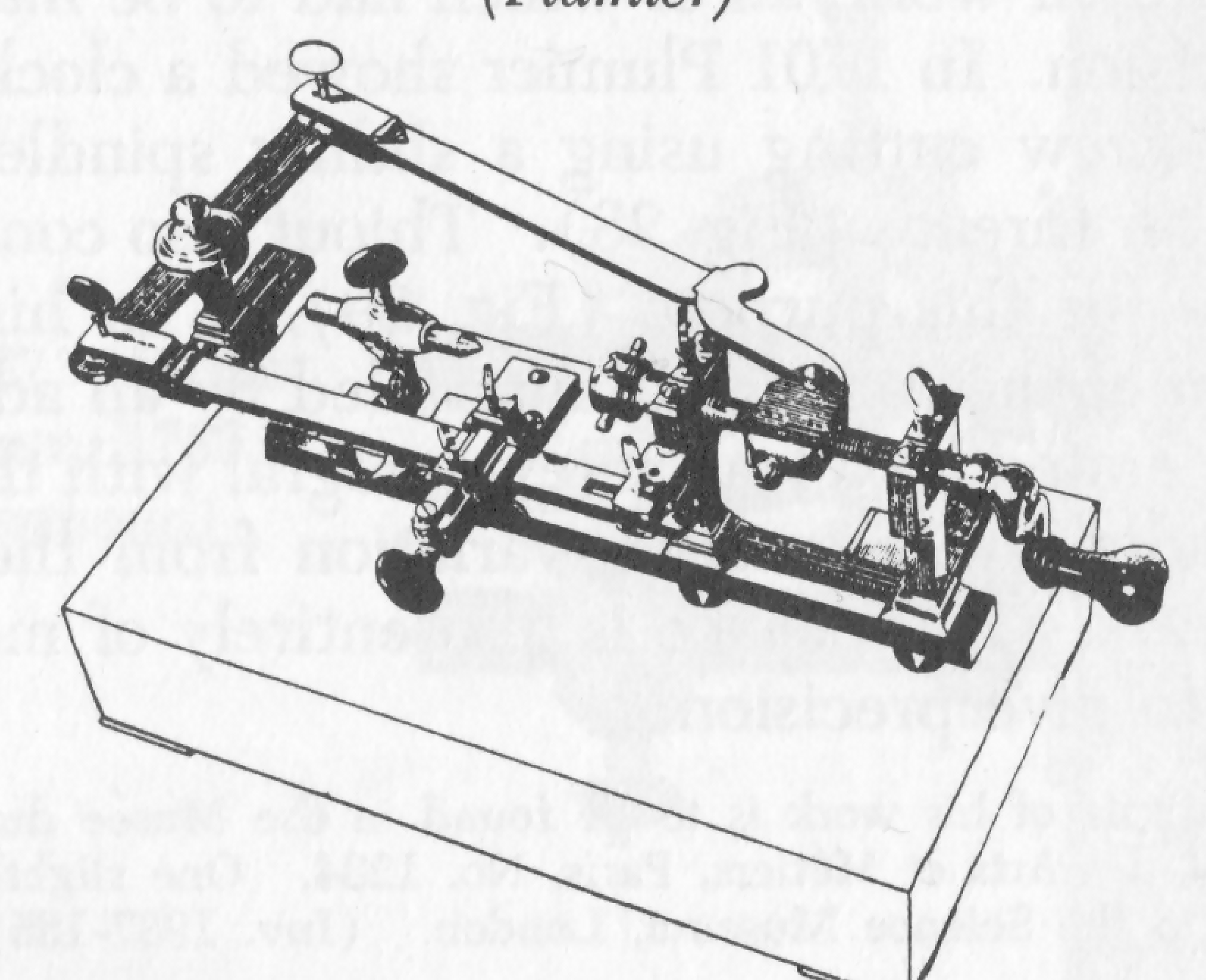


Fig. 29. Thiout's Screw-cutting Lathe for a Clockmaker, 1741.
(Thiout)

For simple turning the instrument maker commonly used a pole lathe, not very different from that of the wood turner.[37]

The instrument makers also had their own special problems which could not be solved by ingenuity and hand skill. Many involved the construction of an accurate screw—either as a means of precision division of the circle or of a line, or for use in micrometer devices used at this time only for various scientific instruments.[38] Both Ramsden[39] and de Chaulnes[40] used such screws; but Ramsden's method of making them, as the more successful, may better be described.

In Ramsden's devices for dividing the circle and for graduating a scale he was attempting to obtain the utmost precision. The crux of his problem was to get a screw cut as precisely as possible in order to make accurate sub-division of the basic graduations of his circular dividing engine.

Ramsden's first step in graduating the large wheel for his circular dividing engine was to step off the scale as exactly as he could into 240 divisions, each intended to contain exactly 9 teeth of a tangent screw. This tangent screw had been cut on the special screw-cutting lathe shown in Figure 30. Here Ramsden recognized the value of a triangular guide bar, since only two surfaces have to be finished to exact planes to give precision. Using the best available lead screw and change gears, the diamond cutting tool generated a precision

37. Diderot and d'Alembert, *Encyclopédie,* Paris, 1767, Planches: Vol. 5, "Instruments de mathématiques," Plate 1.

38. For an excellent and full account of these problems in their scientific and cultural setting see Maurice Daumas, *Les instruments scientifiques aux XVIIe et XVIIIe siècles,* Paris, 1953.

39. J. Ramsden, *Description of our Engine for Dividing Mathematical Instruments,* London, 1777; *Description of an Engine for Dividing Straight Lines,* London, 1779.

40. Chaulnes, Duc de, *Nouvelle méthode pour diviser les instruments de mathématiques,* Paris, 1768.

thread in the hardened steel screw to be used in cutting the teeth on the wheel of the circular dividing engine. Using a microscope and careful repetition Ramsden cut the teeth in the wheel to a very high order of accuracy, but found that 9 threads of this tangent screw did not correspond exactly to each of the 240 divisions he had previously inscribed, by about one thread in 100. A new screw was then cut from this one, using change gears in a ratio of 198 to 200.

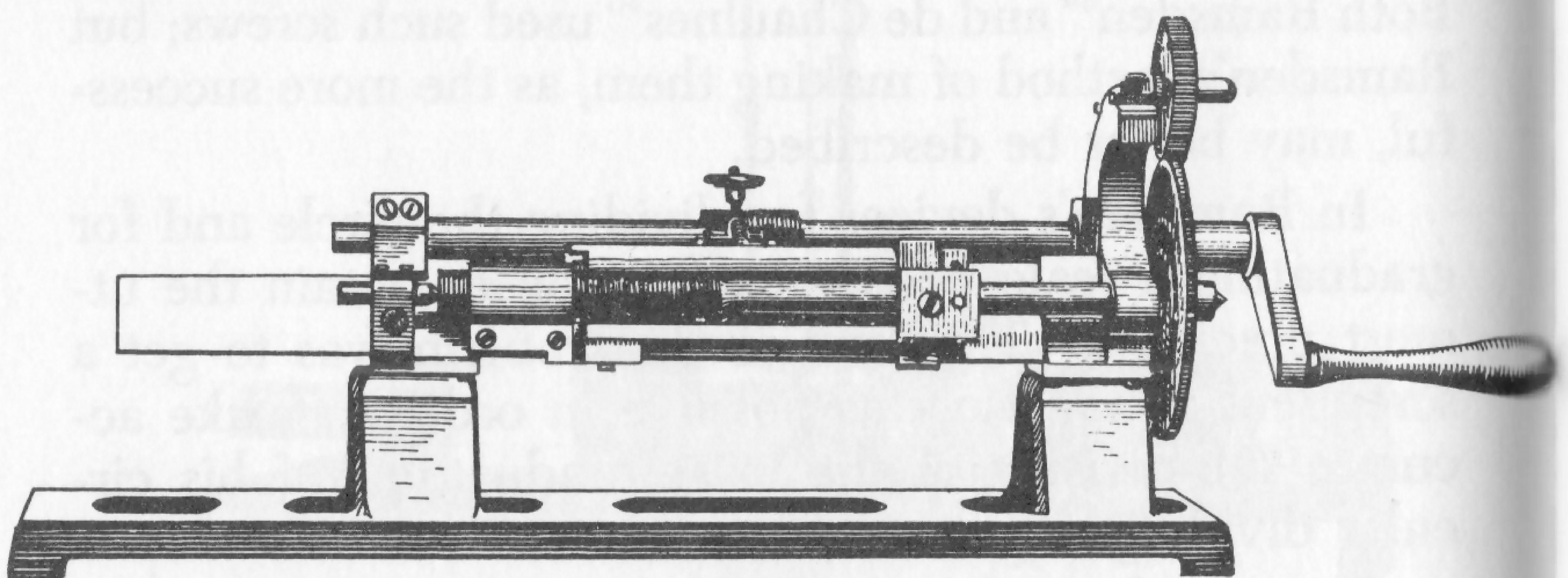


FIG. 30. PRECISION SCREW-CUTTING LATHE, 1777.
(Ramsden)

For the screw of his dividing engine for straight lines, Ramsden used the lathe shown in Figure 31. The large wheel is moved by a tangent screw "G" cut to have as exactly as possible 20 threads to the inch. The tangent wheel has a central boss or pulley "p" to which is attached one end of a strip of spring steel. The other end is attached to the slide carrying the cutting tool. The diameter of the central boss is adjusted until 600 turns of the hand crank give exactly 5 inches of travel. By the gearing shown, this motion is coordinated precisely with the rotation of the tangent screw to cut the final screw. With this device one could cut a lead screw of great precision and of any desired length.

To be sure, these lathes of the clock and instrument

makers are highly specialized and are not industrial machine tools, but they were made entirely of metal and with the greatest precision—two elements that were to enter into the industrial lathe through Maudslay's wide acquaintance among men of these crafts.

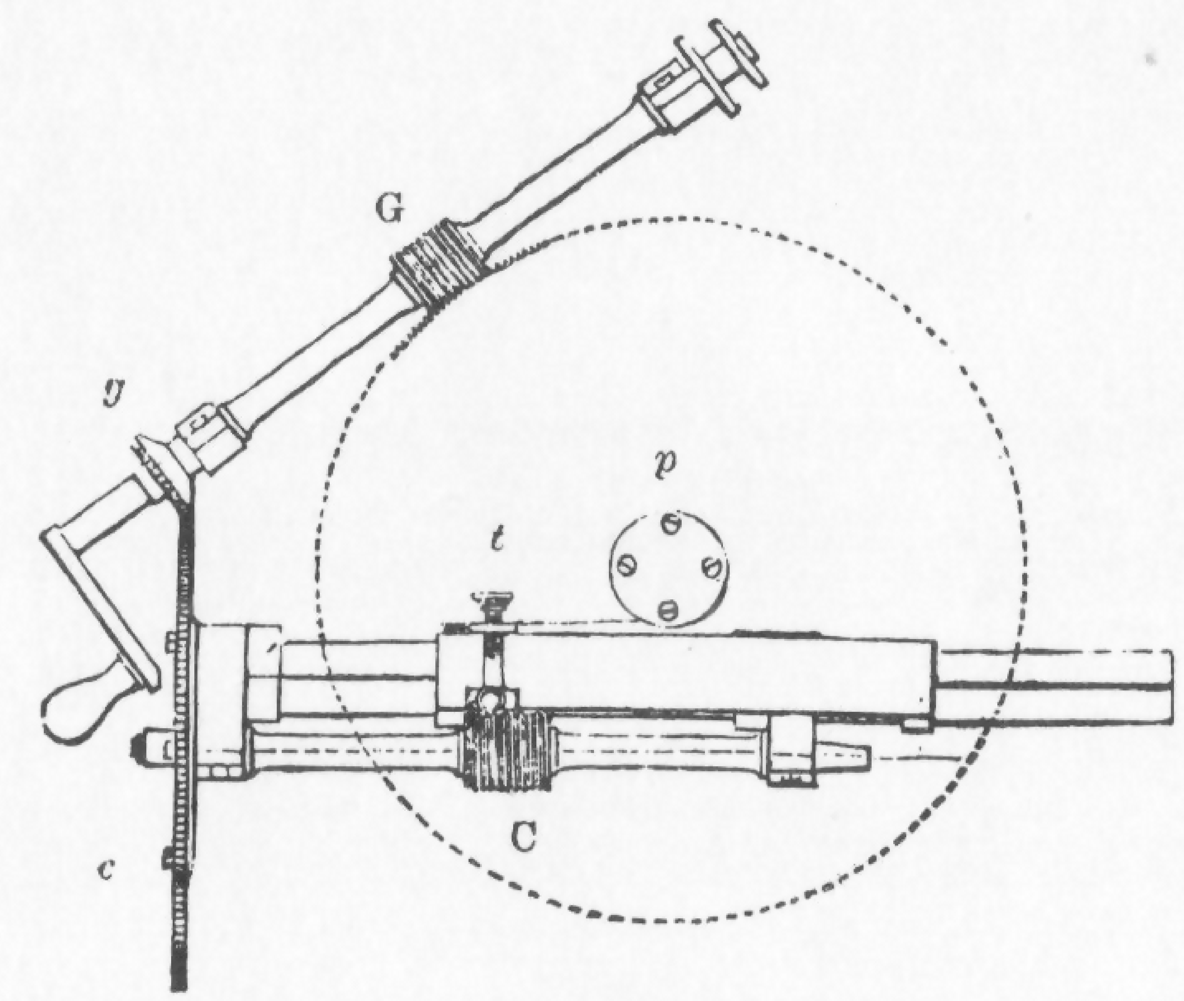


FIG. 31. PRECISION SCREW-CUTTING LATHE, 1778.
(Ramsden)

III Birth of the Industrial Lathe

THE EARLY INDUSTRIAL LATHES

THE FIRST IRON-CUTTING LATHES

We have seen the lathes common in industrial practice in the 16th century as depicted in Amman's series of wood cuts. Figure 14 shows the metal-cutting lathe of that century. He also shows a wood turner who makes plates, balls, little jewel boxes, furniture legs, and handles for hammers, using a pole lathe of the type already in use in the 14th century. In the 17th century the pole lathe is clearly in use with very little change, as is apparent in the copperplate engravings of J. J. van Vliet of 1635.[1]

THE EARLY INDUSTRIAL LATHES

In the latter half of the 17th century the growth of the features of the modern industrial lathe which we have traced from the 15th century through da Vinci, Besson, and de Caus is continued. Chérubin d'Orléans, writing in 1671,[2] describes in some detail an interesting combination of the bow drive and the crank flywheel. But the most important feature of this drive is the use of several pulleys of different sizes mounted on the overhead shaft so that different speeds of revolution can be obtained, a great advance in flexibility and convenience, even though there is no corresponding step pulley on the lathe spindle and different cords would therefore be required for each speed.

1. *Münchener Kupferstichkabinett,* B46. See also Friedrich Friese, *Künstler und Handwerker Ceremonial-Politica,* Leipzig, 1708, pp. 232-301. Of little use for the technical features, Friese is full of information about the guild of turners. Their products and their royal and noble patrons are also included, in a verse of 1653 by Joachim Müllner.

2. Chérubin d'Orléans, *La dioptrique oculaire,* Paris, 1671, pp. 393-415, Plates 54-59. Chérubin is in the line of a number of inventors attempting to produce, by mechanical means, lenses or laps for grinding them. Specialized tools for this purpose, some of which resemble lathes, are to be found in Leonardo, in Emanuel Maignan, *Perspectiva Horaria,* Rome, 1648, and in many later writers. See R. S. Woodbury, *History of the Grinding Machine,* Cambridge, Mass., 1959.

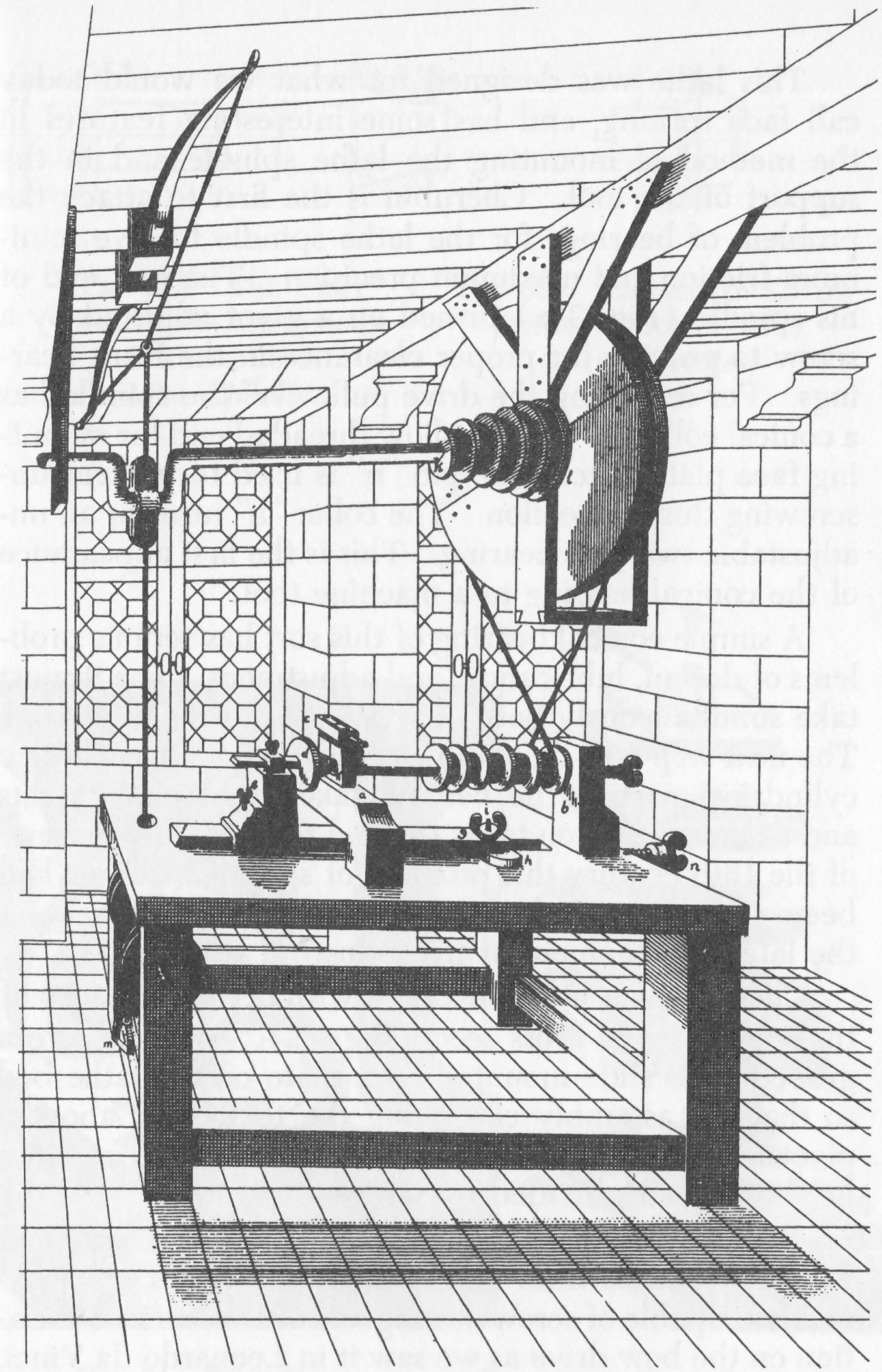


FIG. 32. LATHE WITH VARIABLE SPEED DRIVE AND GIBBED SLIDE, 1671. *(Chérubin)*

This lathe was designed for what we would today call face turning, and has some interesting features in the method of mounting the lathe spindle and in the support of the tool. Chérubin is the first to attack the problem of bearings for the lathe spindle to give minimum friction and maximum precision. The rear end of his spindle (Fig. 33a) turned on a pivot adjusted by a screw to provide for proper clearance in the front bearings. For mounting the drive pulley "r" the spindle has a conical collar "a" and a hollow threaded end for mounting face plates, etc. The pin "b" is used to prevent unscrewing this connection. The collar "a" turns in an unadjustable two-part bearing. This is the first appearance of the conical bearing in a machine tool.

A simple conical bearing of this sort has serious problems of design, lubrication, and adjustment, since it must take simultaneously both end thrusts and radial thrusts. The next step was shown in Geissler (Fig. 33b) where a cylindrical part of the bearing takes the radial thrusts and a conical portion takes the end thrusts.[3] By the end of the 18th century this problem of spindle bearings had been seriously attacked—a most important element in the later development of the industrial lathe.

Chérubin was also concerned with better guidance of the toolholder in cross feed (Fig. 32). We see here a gibbed cross slide mounted on a plate on the lathe bed so that the assembly can swing the toolholder about a pivot for turning spherical shapes. In other cross slides he shows feed provided by screws.

Plumier passes lightly over the industrial lathes of his time, but he does describe several lathes of clockmakers capable of screw cutting and with a curious variation on the bow drive as we saw it in Leonardo da Vinci, (Fig. 28). He also shows us a wood turning lathe of his

3. Johann Gottlieb Geissler, *Der Drechsler,* Leipzig, 1795.

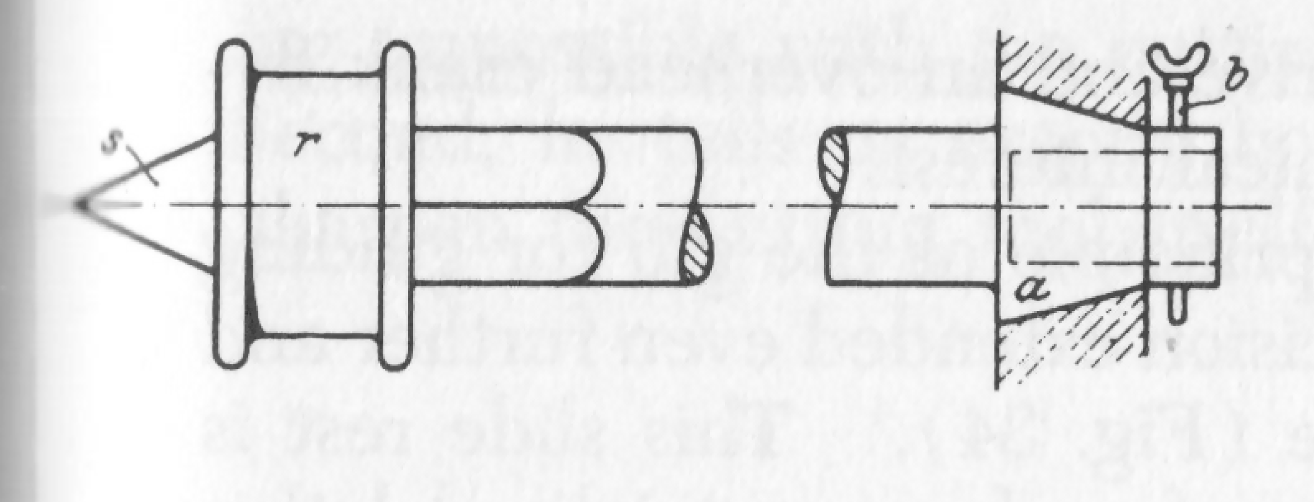


FIG. 33a. THE FIRST CONICAL LATHE SPINDLE BEARING, 1671. (After *Chérubin*)

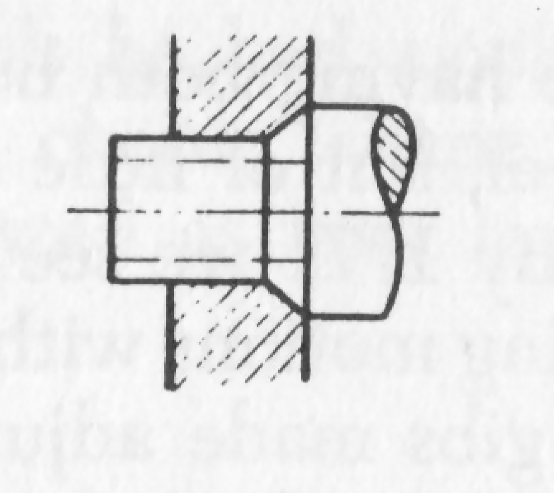


FIG. 33b. DEVELOPED LATHE SPINDLE BEARING, 1795. (After *Geissler*)

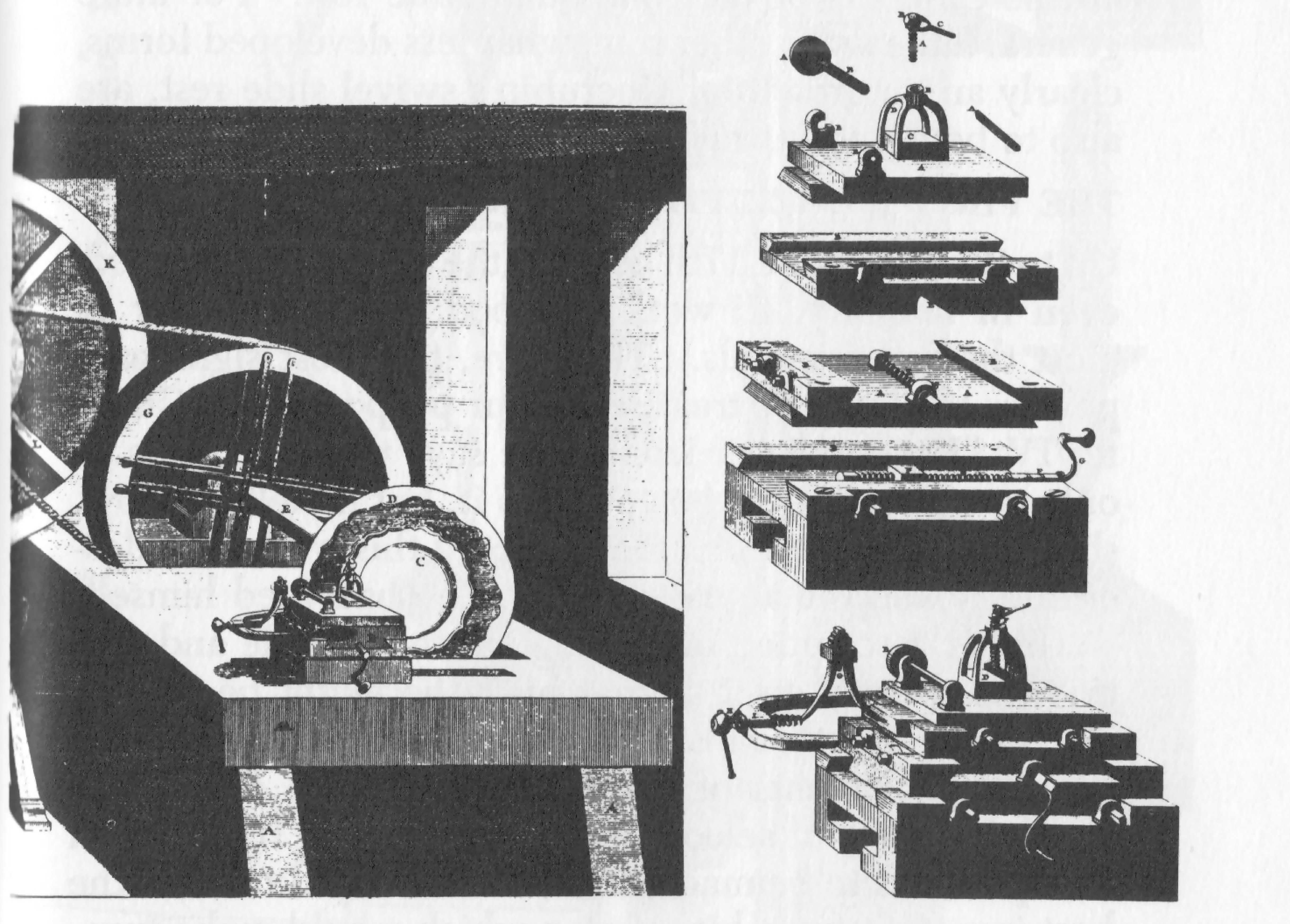


FIG. 34. ROSE ENGINE WITH COMPOUND SLIDE REST AND ADJUSTABLE GIBS, 1771. (*Diderot*)

time having both bow drive and an overhead crank flywheel, but of little technical interest.

By 1771 we see this principle of the gib for guiding sliding motions with precision extended even further and the gibs made adjustable (Fig. 34).[4] This slide rest is for a rose engine and therefore for a specialized lathe, but as can be seen it is an industrial machine, not a hobbyist's device. As will be noted, the upper slide is the toolholder, moving in a gibbed slide operated by a shaft from a cam which forces it to follow the pattern "D" against a spring. The lower plates provide feed in two directions, also in adjustable gibs, by means of screws operated by hand cranks. Here in 1771 we have all the elements of the compound slide rest. For more general lathe work other somewhat less developed forms, clearly an outgrowth of Cherubin's swivel slide rest, are also to be found in this same work.

THE FIRST IRON-CUTTING LATHES

Up to the end of the 17th century the lathe was intended, even in industry, to work in wood, horn, ivory, or at most the softer metals. Therefore, the most significant portion of Plumier's treatise for our purpose is his Chapter IV, "How to Turn Iron." He says that he knows of only two other men who could do it, but he tells us how, shows us the tools and lathe for doing this work, and describes as well the actual technique he had used himself.

In his description of turning an iron spindle and cutting the threads on it so that his lathe might be able to cut threads in other material, Plumier reveals some most important elements of this work. First, he tells us in some detail about selection of the iron stock from which the spindle is to be made, for it was essential to have the best iron, free from bits of slag which would make turn-

4. Diderot, *loc. cit.*, Planches: Vol. VIII, "Orfèvre Grossier," Plates XVII, XVIII.

ing impossible with the cutting tools he had available. Second, he tells us exactly how to choose, shape, and sharpen the cutting tool itself, as well as how it must

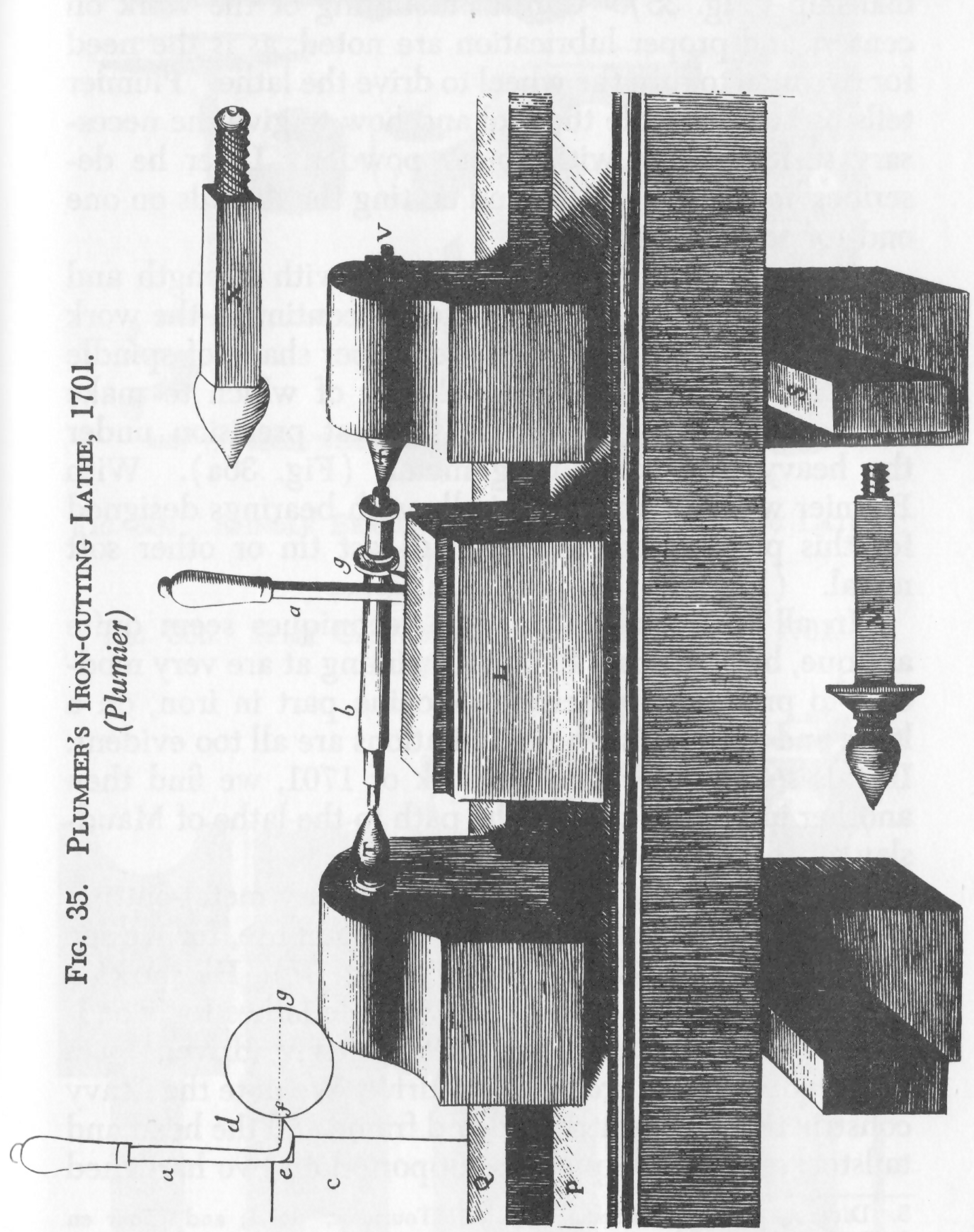


Fig. 35. Plumier's Iron-cutting Lathe, 1701. (*Plumier*)

be held, manipulated, and kept cool so as not to draw its temper. Third, the lathe for turning iron is described, with emphasis on strength, rigidity, and finish of workmanship (Fig. 35). Careful mounting of the work on centers and proper lubrication are noted, as is the need for two men to turn the wheel to drive the lathe. Plumier tells us how to guide the tool and how to give the necessary surface finish with emery powder. Later he describes boring the spindle and cutting the threads on one end for screw cutting.

Not only was Plumier concerned with strength and rigidity for his iron cutting lathe, he continued the work of Chérubin and Geissler on the proper shape of spindle bearings and the best materials out of which to make the bearing beds to give the greatest precision under the heavy loads of cutting metals (Fig. 36a). With Plumier we have an iron spindle with bearings designed for this purpose and running in cast tin or other soft metal. (Fig. 36b).

In all his metal cutting the techniques seem quite antique, but the goals Plumier is aiming at are very modern—to produce a precision machine part in iron, on a lathe and with tools whose limitations are all too evident. In this section of Plumier's book of 1701, we find then another important step on the path to the lathe of Maudslay a century later.

By the last quarter of the 18th century metal-cutting lathes of this sort had come into common use, for we see them in Diderot's *Encyclopédie*[5] (Fig. 37). He shows a turner's shop of the time with two pole lathes for woodworking and a third lathe, metal-cutting, driven by a great wheel with a crossed cord drive. We note the heavy construction of the lathe bed and frame and the head and tailstocks. The workpiece is supported on two hardened

5. Diderot, *loc. cit.*, Planches: Vol. X, "Tourneur," Pl. I; and "Tour en fer," Pl. IV.

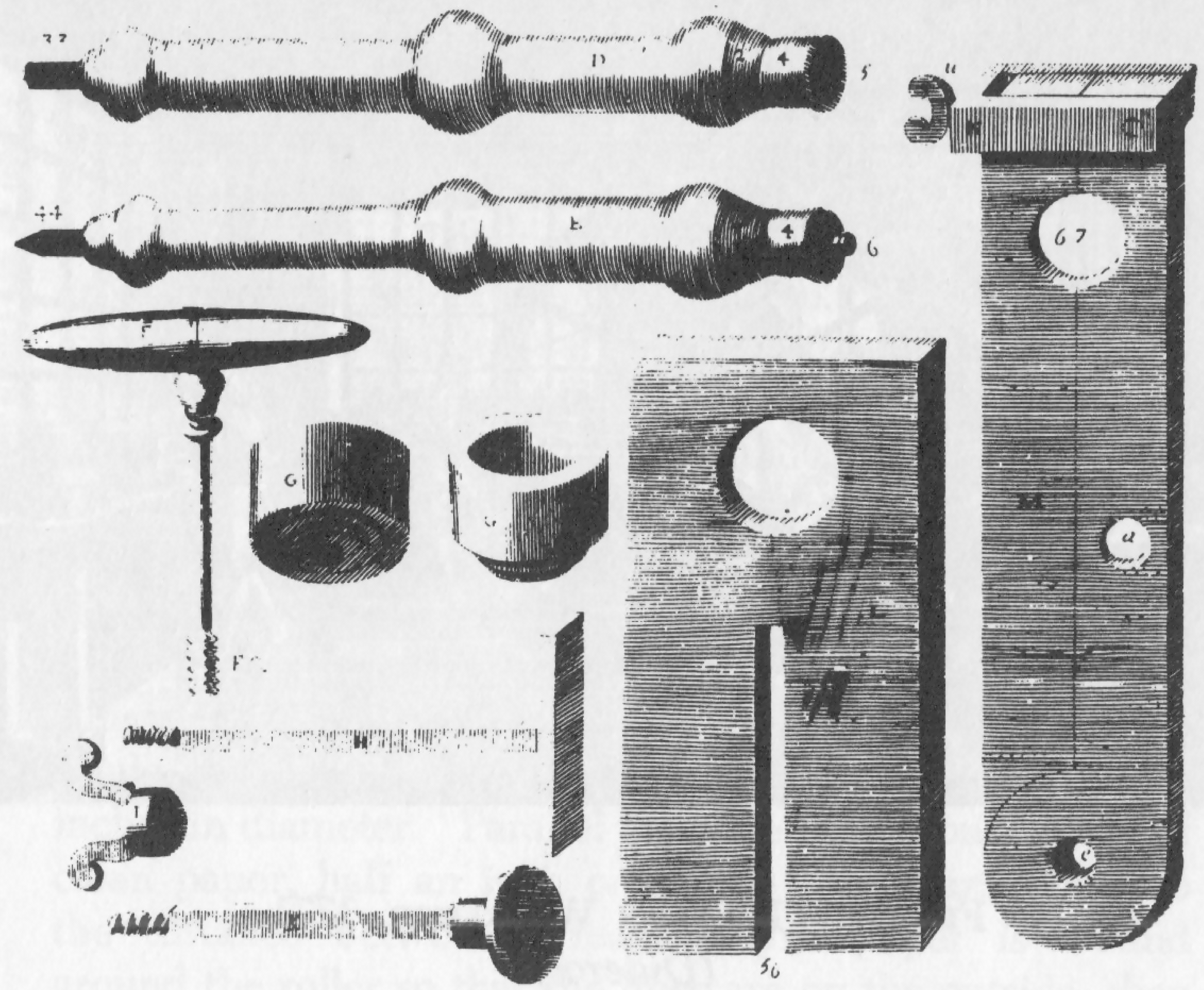
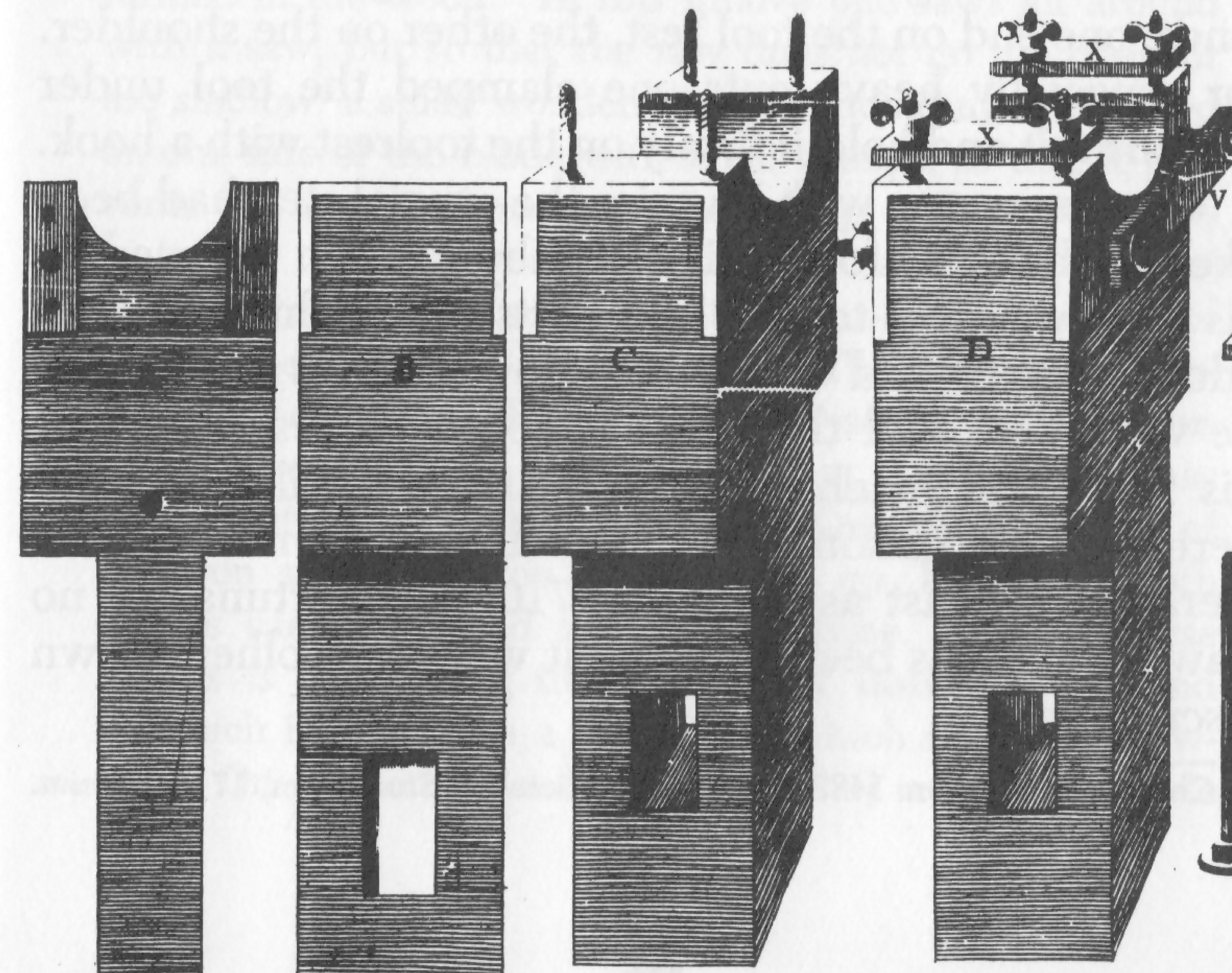


Fig. 36a. Spindle Bearings for the Metal-cutting Lathe, 1701. *(Plumier)*

Fig. 36b. Split Cast Bearings of Soft Metal, 1701. *(Plumier)*



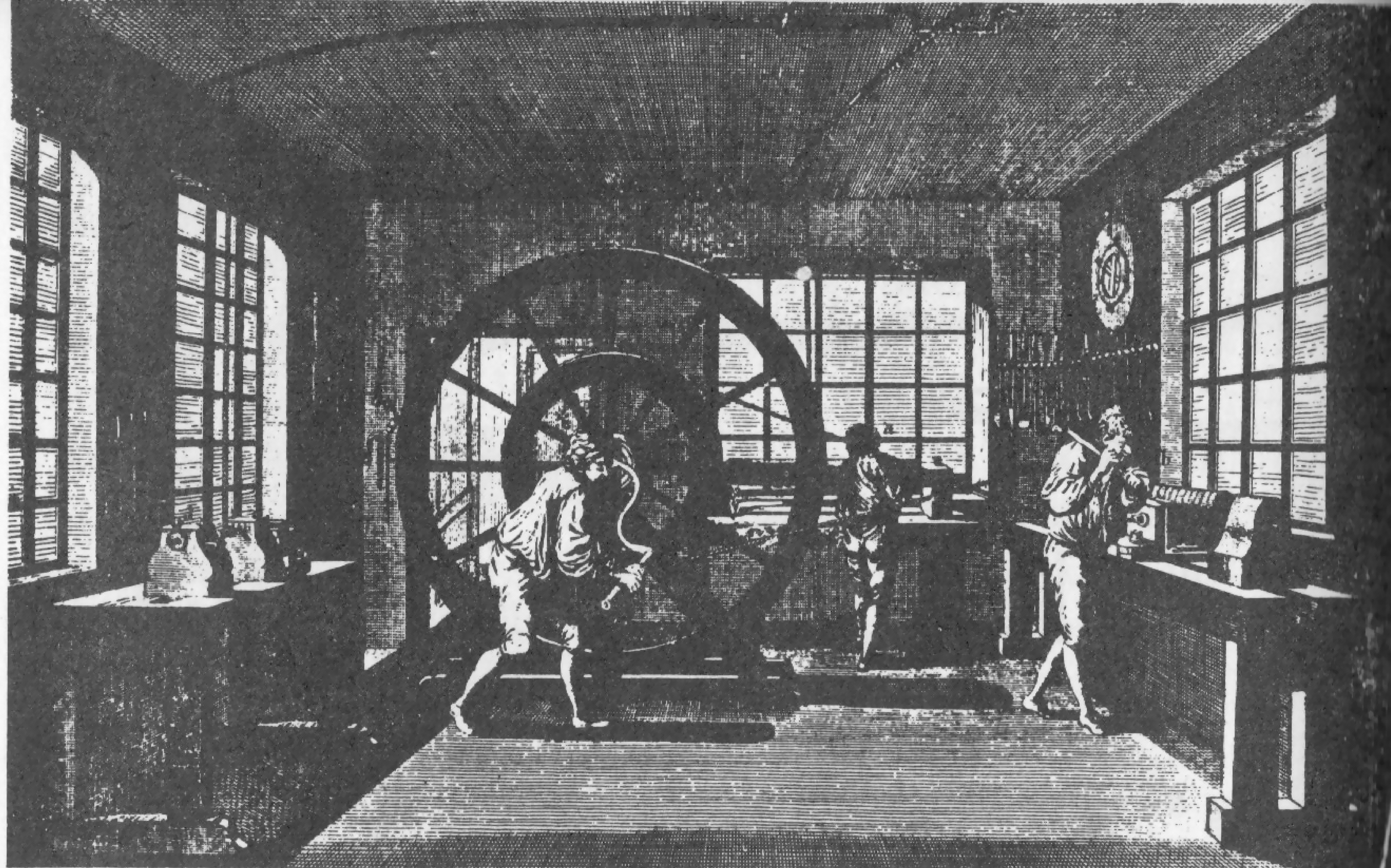


FIG. 37. TURNER'S WORKSHOP, 1771.
(Diderot)

steel centers. Drive is by a wheel, six to nine feet in diameter, through the cord acting on a pulley clamped to the work piece by a kind of screw chuck. There is as yet no mechanical tool holder, much less a slide carriage. The hand cutting tool, about 2½ feet long is held in both hands, one end on the tool rest, the other on the shoulder. For especially heavy cuts one clamped the tool under one's armpit and held it firmly on the toolrest with a hook.

Contemporary with Plumier the crucial step had been taken in the lathe for cutting iron by Polhem in Sweden. His lathe was able to turn iron parts for machinery on an industrial scale and used water power for drive of both the workpiece and the cutting tool. No description of this important machine was published until 1761, but there is good reason to believe that Polhem had it in operation at least as early as 1710.[6] Unfortunately no drawing of it has been found, but we have Polhem's own description:

6. Christopher Polhem MSS in Kungl. Biblioteket, Stockholm, 1710, *passim*.

Now, I will come to the making of rolling machines which is both an art and a science. All kinds of small rollers from 6 to 7 inches in diameter can easily be forged from good iron. They should be covered with steel all around and forged in the proper form. Thereafter, they are set aside for turning. This is best done with a turning lathe run by a small water-wheel. The cutting tool is held by means of a block, which gradually is drawn forward along the roller by a long screw and controlled by the rolling master's own hand. However, it can also be done so that the water-wheel itself is used to turn the screw.

The screw is made thus: First a roller is turned from a hard and fine piece of wood, such as maple, orel or apple, to a length of one aln [60 cm.] and about 2 to 2½ inches in diameter. Parallel lines are drawn on a piece of clean paper, half an inch or a little less apart, equal to the distance between threads. This paper is wound around the roller so that the lines are on the outside, then it is laid together in such a manner that the lines make a spiral, and it is wound with a strong thread or string which runs between the lines the whole way. When this is done and the ends fastened with tacks, a sharp knife is used to press through the paper so that a groove is formed in the wood. In this groove one saws all around with a saw, but so that the saw does not go too deep or too shallow a small wooden piece of moulding is fastened on one side of the blade with small clamps, so that it prevents the sawing from going too deep. The iron screw to be cut is set between two supports each with [square] holes through them such that the four-cornered ends of the iron screw can fit right through. Then there is a four-cornered casing so that the wooden screw with a four-cornered end can be set in the casing opposite, but has its puppet head on the other end. On the other end of the iron screw an iron crank is set up, by which both screws can be rotated at the same time. Against these screws is put a long iron instead of fasteners, one end of which is bent with a thin blade which fits in the sawing. On the other end [of the lathe] a hole is made

large enough so that turning tool can go through it and is fastened with a steel screw in the usual manner. When everything is in order the crank is turned around so that the turning tool runs from one end to the other and is pressed [in] with a piece of iron. In this way several turns are completed until the threads are deep enough, that is, equal depth and equal threads. The rest common sense and thought should decide, but I will come to the steel rolling machine later.

When the screw is completed at the water-wheel it is fastened in a steady turning lathe run by wheels and adjusted thereafter with smaller pieces of iron and filed to its correct diameter and smoothness. Then it is hardened by first heating it red hot in the fire and then dipped gradually in slowly flowing water.[7]

There was nothing new about Polhem's method of laying out a screw; it was clearly known to Leonardo da Vinci. The method of cutting the lead screw for Polhem's lathe was known to the author of the *Mittelalterliches Hausbuch* in 1480, (See Fig. 15) except that Polhem's original wooden screw is not fitted to a nut but is advanced by use of the principle shown in Figure 17. None of this was new, but Polhem's use of these known methods to cut a substantial screw of iron which is "completed at the water wheel" was original and important, even though final finishing had to be done by handwork in a lathe. We should not fail to note that Polhem's lead screw was hardened to reduce the wear which would result from the heavy use to which he put it in his lathe for turning rollers for rolling mills of an industrial size.

Unfortunately Polhem is not as detailed about the lathe in which this lead screw was to be used. Clearly it was provided with water power to drive the work piece—a heavy steel and iron forging and weldment. The same water wheel could also be used to feed the

7. Christopher Polhem, *Patriotiska testamente,* Stockholm [?], 1761, pp. 60-62.

cutting tool along the work. The lathe itself must then have been of very heavy construction. Polhem's other work could lead us to expect this heavy lathe to have been principally of wood, essentially a larger and heavier version of the iron-cutting lathe of Plumier, but with some most important additions. On the other hand, Polhem was rolling iron bars and plates of dimensions and quality fully adequate for him to have made his lathe bed, stocks, and carriage of that material. He was also already making castings and forgings for other purposes in sizes and shapes adequate for his lathe. Unfortunately, the evidence available does not allow us to decide this question.

There can be no doubt that Polhem had a lathe with a tool carriage driven by a lead screw and gears to give longitudinal feed of the cutting tool, either manually or by power. This cutting tool acted on a heavy workpiece turned by power. It is equally evident that rather accurate results were obtained, for Polhem later tells us that even after these rollers were hardened they could be trued up simply by a grinding device invented by his son Gabriel in 1737.

One other question remains before we leave this most important lathe. What influence did it have on the methods of manufacture in Sweden and in other countries? This question is a part of the as yet unresolved problem of the influence of Polhem's many anticipations in technology. We know that Polhem travelled extensively in other countries, but as yet no record of what he left there or brought back with him has come to light. We know that his pupil and enthusiastic advertizer Emanuel Swedenborg travelled extensively in France and to England, but again we have little evidence of just how much of Polhem's work he spread abroad.

We can only conclude that Polhem had anticipated much of Maudslay's work two generations earlier, but that he clearly did not have the wide and important in-

fluence on manufacturing that made Maudslay's work so significant.

Although we cannot be sure that Polhem's industrial iron-turning lathe of about 1710 had a heavy iron or steel frame, by about 1760 we have the industrial lathe of Vaucanson now in the Conservatoire National des Arts et Métiers.[8] As can be easily seen in Figure 38, this lathe has a very heavy framework of iron bars solidly bolted together. Provision is made for mounting the workpiece between substantial centers. These are longitudinally adjustable but only through a rather limited range, which suggests that this was not a general purpose lathe, rather one designed to produce a number of similar parts of whose character and use we know little. However, this lathe can take a workpiece about 40 inches in length and about 12 inches in maximum diameter. The means of driving the workpiece is not known, but was perhaps some sort of belt or cord drive acting directly on the workpiece.

The lathe guideways consist of two iron bars about 1.5 inches in square cross section, each so mounted as to provide two bearing surfaces for the carriage at 45 degrees to the horizontal. Very heavy supports are provided at intervals along the length of these guide bars. Vaucanson had clearly recognized the merits of prismatic guideways for the carriage, such as freedom from dirt and chips, ease of obtaining precision, and improved support of the carriage. This feature was later used by Maudslay.

The heavy carriage itself is of brass and carries a cross slide on which the toolholder is mounted. The cross slide has a screw to permit accurate feed of the tool into the work, but there are no divisions to make possible accurate readings of the actual amount of cross feed.

8. *Catalogue du Musée, Mécanique*, Paris, 1956, pp. 123-126.

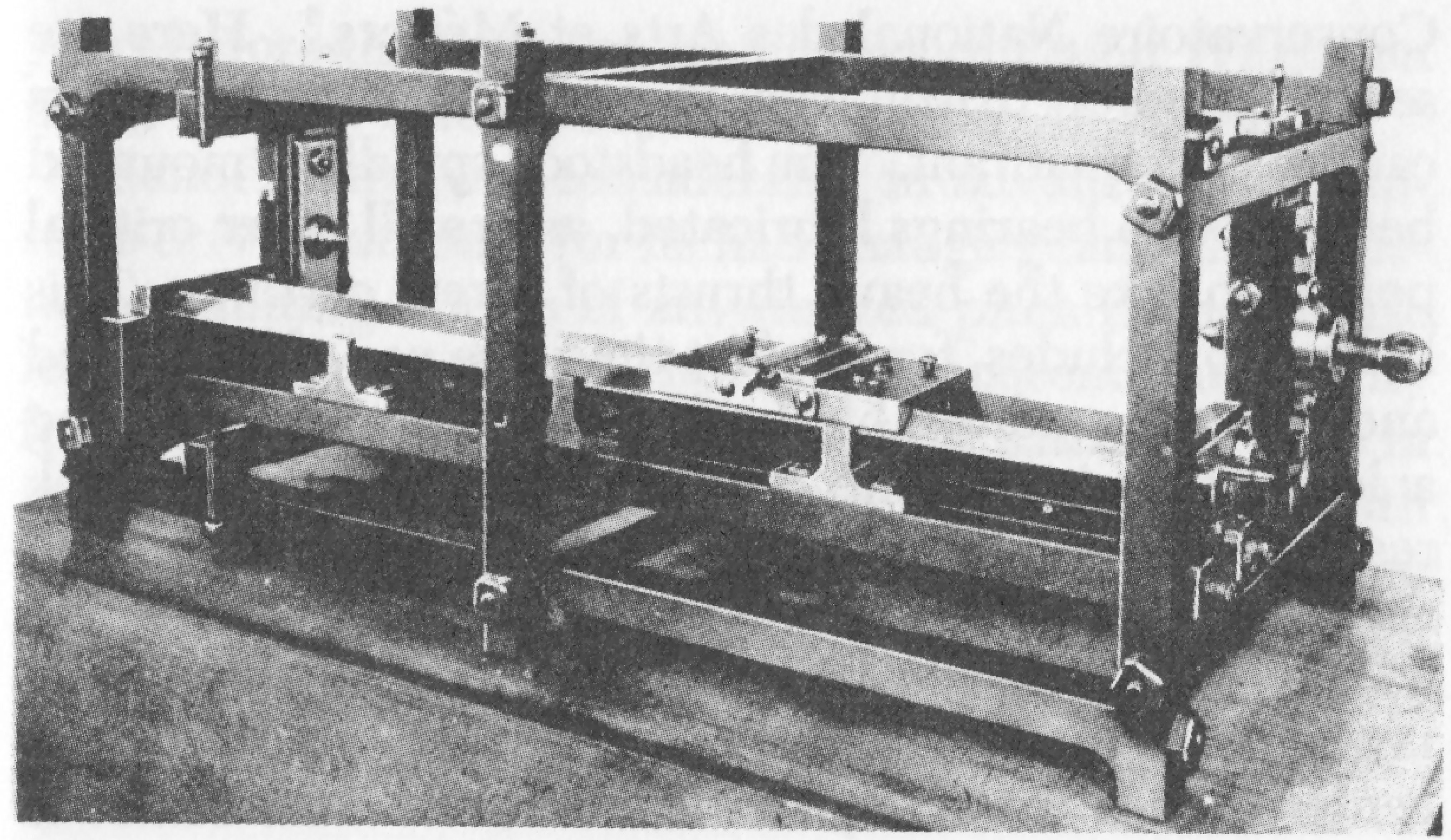


FIG. 38. LATHE OF VAUCANSON, 1770-1780.
(Conservatoire National)

This cross slide is less highly developed than that of Chérubin d'Orléans of 1671 (Fig. 32), or the one shown by Diderot in 1771 (Fig. 34), but it is far more substantial and therefore capable of doing accurate work on iron workpieces of industrial dimensions. The carriage is fed longitudinally by a lead screw manually operated from either end. Both centers can be adjusted transversely and vertically so that exact alignment of centers could be easily obtained by trial cuts on a workpiece.

Vaucanson's lathe must have been rather inconvenient to use, and the apparent limitations in its drive of the workpiece and the failure to construct the carriage of iron must have limited the operator to very low rates of metal removal. However, it does show quite clearly that many features of Maudslay's lathes for heavy industrial turning of iron had been anticipated by at least a generation in France.

Leonardo da Vinci's suggestion of the use of change gears in a lathe designed primarily for screw cutting (Fig. 18) was revived in an industrial lathe by Senot dating from 1795 (Fig. 39). This lathe is also in the

Conservatoire National des Arts et Métiers.[9] Here we see a lead screw driven from the spindle by change gears carried on a quadrant. The headstock spindle is mounted between two bearings lubricated, as are all other critical points, to take the heavy thrusts of screw cutting. This lathe also includes, for the first time, the use of both fixed and following adjustable back rests to prevent bending a long workpiece while cutting. One adjustable back rest is even mounted directly on the carriage to oppose the thrust of the cutting tool. The workpiece is held at one end by a simple set-screw chuck mounted on the headstock spindle. The other end is supported by a live center carried in an adjustable tailstock. This center is itself supported in a rather curious way which permits longitudinal adjustment but does not assure precise alignment with the axis of the headstock spindle.

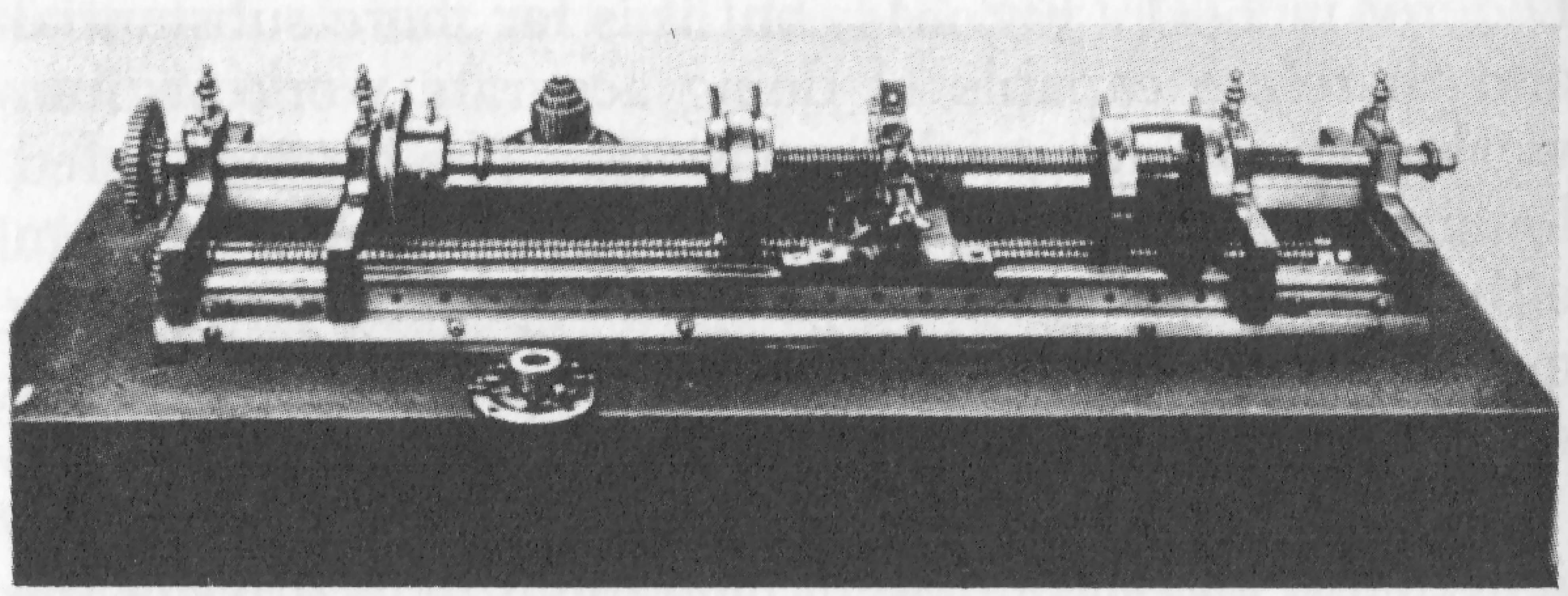


FIG. 39. SCREW-CUTTING LATHE OF SENOT, 1795. *(Conservatoire National)*

Heavy construction throughout this lathe shows that Senot also had in mind heavy industrial work, and his design is far more advanced and convenient to operate than that of Vaucanson. Clearly, his lathe utilizes on an industrial scale the principle of screw cutting by means of a master lead screw and change gears three

9. *Ibid.*, pp. 126-127.

years before the screw-cutting lathes of David Wilkinson in the United States or Henry Maudslay in England.

Senot's lathe was considerably in advance of Wilkinson's or Vaucanson's, for he had change gears which permitted cutting screws of any desired pitch from a single lead screw, even though they were apparently used only for that purpose and not for varying the feed rate in general turning. He was also much more concerned with *precision* than these other two lathe builders, as we can see from his use of back rests, better mounting and design of his carriage, and location of the lead screw directly under the workpiece.

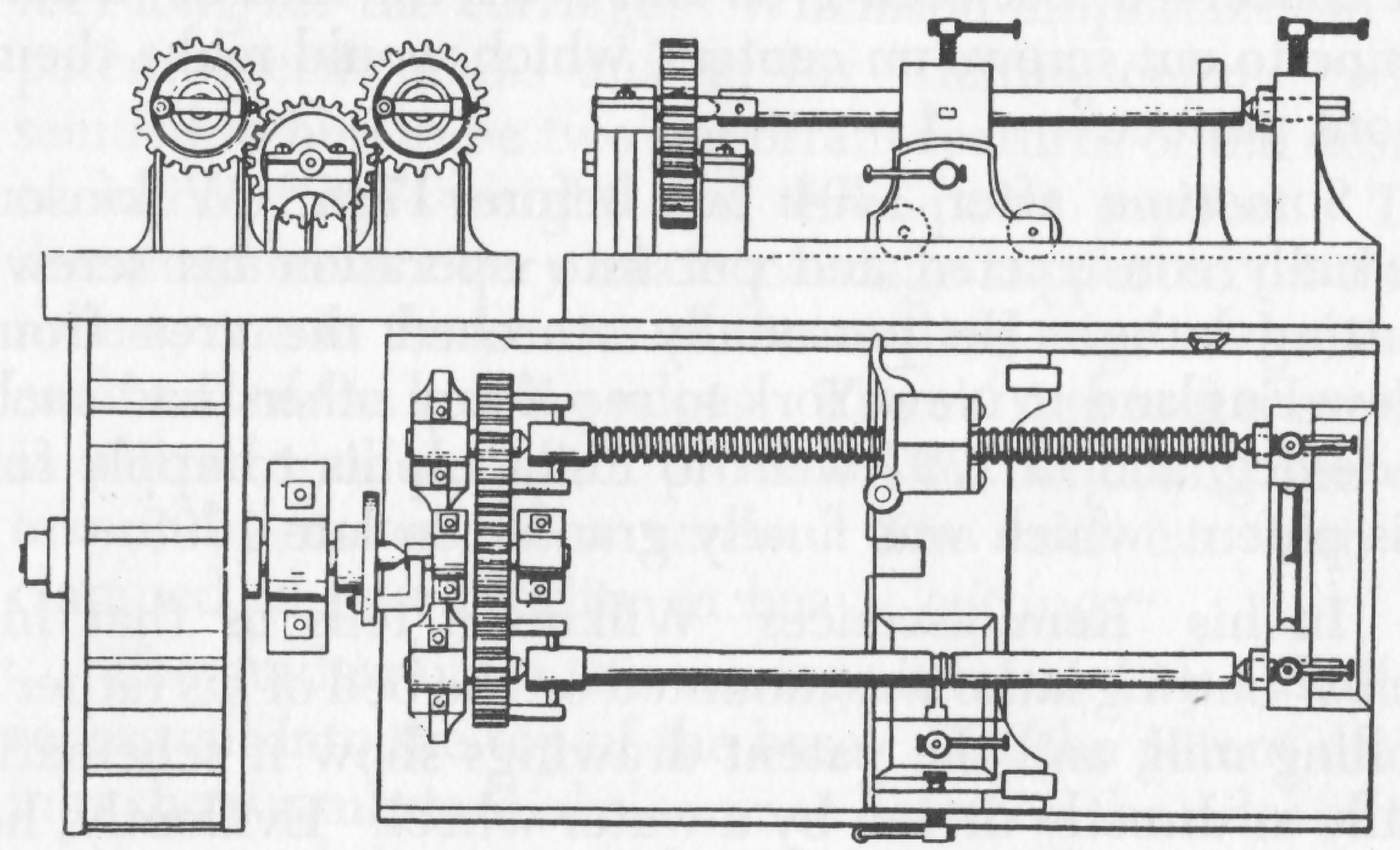


FIG. 40. WILKINSON'S SCREW-CUTTING LATHE, 1798. *(American Machinist)*

The lathe of David Wilkinson is in many respects a rather odd mechanism, but it is of interest if only as showing increasing world-wide concern with the problem of an *industrial* lathe.

As shown in Figure 40,[10] the Wilkinson lathe of 1796

10. Redrawn from part of the patent drawings in the U.S. National Archives, themselves redrawn May 5, 1845, presumably from the original drawings. Wilkinson's patent specifications of December 14, 1798 were

is clearly only a screw-cutting machine tool and one limited to reproducing screws with the same pitch as the original lead screw. From his later account of his invention of this device[11] Wilkinson had obviously had wide experience in producing large industrial screws by casting and by handwork. He had also built steam engines of substantial size, as well as machinery for canal locks and draw bridges. In making new types of textile machinery for Samuel Slater and others[12] Wilkinson had turned many of their iron parts upon a hand lathe. Dissatisfied with the accuracy of the industrial screws then being made for oil mills, clothier's presses and for paper mills, he conceived, between 1788 and 1794, the idea of "a machine to cut screws on centers, which would make them more perfect."

Sometime after 1794 but before 1796[13] Wilkinson actually constructed and put into operation his screw-cutting lathe. He personally searched the area from New England to New York to see if any others had such a device, and in 1797 went to Philadelphia to apply for his patent, which was finally granted in late 1798.

In his "Reminiscences" Wilkinson tells us that his screw-cutting lathe was mounted on the bed of his father's rolling mill, and the patent drawings show it schematically as directly driven by a water wheel. Evidently, he

lost in the Patent Office fire of 1836, but can be found in the U.S. National Archives in the *Restored Patents* as No. 220, Vol. I, p. 289. The author has been unable to find any patent or other evidence for a lathe with a slide rest of 1791 attributed to Sylvanus Brown in Massena Goodrich, *Historical Sketch of the Town of Pawtucket*, Pawtucket, R.I., 1876, p. 48.

11. "David Wilkinson's Reminiscences," in *Trans. Rhode Island Society for the Encouragement of Domestic Industry, 1861*, Providence, R.I. 1862, pp. 99-118. Wilkinson dated these memoirs December 1, 1846.

12. In this connection he had invented a primitive centerless grinding machine. See R. S. Woodbury, *History of the Grinding Machine*, Cambridge, Mass. 1959, p. 33.

13. Timothy Dwight, *Travels in New England and New York*, 4 Vols., 1821, Vol. II, p. 27.

later powered it by a horse gin.[14] Simple gearing and dogs drive the lead screw and the workpiece, which are both mounted on centers. The headstock arrangements are of heavy construction throughout. No change gears are mentioned, and so Wilkinson could cut threads on this machine of only the same pitch as his lead screw. A heavy tailstock is provided, and the dead centers can be adjusted through a small compass and clamped, but the tailstock does not slide and Wilkinson could therefore cut screws of only nearly the same length.

The single heavy base supports the tailstock and the headstock arrangements and provides a guideway 18 - 20 feet long for the carriage. Wilkinson emphasizes in his patent specifications and in his "Reminiscences" what seemed to him to be two important features of the design of his carriage—weight and three-point support. The drawing shows a very heavy carriage supported on three rollers, one in the center of the trailing edge and one on each end of the leading edges. The cutting tool is carried in a fixed tool rest with provision for adjusting the cut taken, by means of a screw. The tool can also be clamped to give rigidity in heavy cutting.

The guideway for this carriage is formed by a shallow recess cut into the top of the base. But the patent drawings show a substantial clearance between the sides of the carriage and the inner sides of this recess. Clearly any tendency of the carriage to cant would be met only by the clamping of the half nuts on the lead screw, a feature which would hardly lead to precision work. One is also led to speculate just how accurate the bed of this guideway may have been in an age that did not know the planer; Wilkinson does not tell us how it was to be made. Nor do we have any idea how accurate his lead screw may have been.

14. *Ibid.*

The drive of the carriage was by means of two half nuts which could be clamped to the lead screw, and had the interesting feature of an automatic release when the spring-loaded clamping lever struck an upright near the tailstock. Wilkinson's patent drawings also show an ingenious attachment for this machine by which the corresponding nuts could be cut, using a kind of fly cutter mounted on a shaft carried between the workpiece centers.

This machine has only limited flexibility and it certainly was not a precision tool, but it was a useful and successful device of industrial size and capacity.

Despite the fact that his patent described only "a machine for cutting screws" Wilkinson had tried to persuade Slater to let him construct a general purpose "slide lathe, on the principle of my screw machine, which was made for large turning," but it was considered to be too heavy for machining the light parts of textile machinery. Slater imported a man from England to build a lathe suitable for turning rollers. This lathe was built with a slide rest running on a kind of gibbed guideway, but it proved to be unsatisfactory and was abandoned.

Wilkinson then built a general purpose lathe for industrial work based upon a modification of his screw-cutting machine. It incorporated his old principle of weight but abandoned the three rollers to support the slide rest as unnecessary for reducing the friction for light work and slow motion. "It worked to a charm."

This lathe came into very wide use, especially in the government arsenals, where over 200 were in use in 1848,[15] and saved vast amounts of labor and expense. We can, therefore, be sure that by 1806 David Wilkinson, acting independently, had finally constructed a general purpose lathe with a screw drive of its carriage and suitable

15. Committee on Military Affairs, Report on Senate Bill 187, 1st Session 30th Congress.

for extensive industrial use. Even though we wish we had more details of the actual lathe, which was evidently never patented, in these respects at least he had clearly anticipated Maudslay,[16] for at this time Maudslay did not have any lathe of heavy *industrial* capacity which incorporated screw drive of a slide rest.

Like Maudslay, Wilkinson trained in his shop a whole generation of machinists and machine tool builders who laid the foundations for much of the use of machine tools in the United States.[17] In fact, we may credit David Wilkinson with being the founder of the American machine tool industry and mark him as a contributor of the first rank to the industrial lathe.

In 1800 the time was thus ripe technically for the birth of the modern industrial metal-cutting lathe of precision and large capacity. All that was needed was the economic incentive to bring together these technical elements in the kind of synthesis possible only in the man of genius—Henry Maudslay.

16. See Jonathan T. Lincoln, "The Invention of the Slide Lathe," in *American Machinist*, Vol. 76 (1932), pp. 168-170. Lincoln's attempt to trace the idea of the slide rest from Wilkinson to Maudslay through M. I. Brunel is interesting but purely speculative, as Lincoln admits.
17. *Ibid*, p. 170.

IV The Lathe Comes of Age

MAUDSLAY

ROBERTS AND FOX

WHITWORTH

In order to evaluate properly the work of Henry Maudslay on the lathe we must first analyze the essential elements of the industrial lathe. Then we may ask which of these elements had been known or used prior to Maudslay, what additional elements he supplied, and what use he made of them all in his lathes. And of course, we must consider the influence which Maudslay had, not only on the later development of the lathe, but upon its extensive use in industry after 1800.

For the lathe to take the place it had in industry in 1850 certain elements were necessary, others were merely matters of convenience. Let us consider first those which were essential, for it is they which are most relevant to the contributions made by Maudslay.

An industrial lathe must have: first, the ability to machine an iron or steel workpiece of a substantial industrial size. In order to meet this requirement the lathe must itself normally be made of iron or steel and have its various parts of dimensions such that it can withstand the stresses set up in it by cutting the ferrous metals. Its overall dimensions—swing and length of bed—must also permit mounting a large workpiece for turning.

Second, the industrial lathe must also be supplied with a source of power and means of its transmission to the workpiece and to the cutting tool adequate for cutting iron and steel at rates which are economical. This requires a suitable headstock spindle with means for its drive, and a tool carriage with its feed.

Third, the industrial lathe must itself be constructed with adequate rigidity and precision so that it is capable of producing a precision nearly equal to its own in the workpieces turned on it. This is an additional reason for requiring the lathe to be of iron or steel; wood can neither take nor retain precision, and the non-ferrous metals

available by 1850 could not give the necessary rigidity. Rigidity in a lathe is provided partly by the material of which it is made and partly by the design of its parts, but precision depends also upon the accurate construction of certain of its features, especially the spindle bearings, the guideways, and the lead screw. The precision actually needed in the industrial lathe at any given period is somewhat greater than that required for the work to be done on it.

Fourth, the industrial lathe must have flexibility. Only a few machine shops in the mid-19th century could afford to have specialized machine tools, such as a boring engine, a screw-cutting machine, or a gear-cutting machine. Most shops had to depend upon a lathe, a planer or shaper, and a drilling machine, together with the skill and ingenuity of their workmen. To achieve flexibility the lathe needs at least change gears for both screw cutting and longitudinal feed of the tool, cone pulleys or some other means of varying the speed of the workpiece and the cutting rate, a sliding tailstock to take work of different lengths, and a chuck or a face plate for boring or for doing other turning not possible with the workpiece mounted between centers.

Fifth, the design of an industrial lathe may incorporate many conveniences, but it must have as a minimum those needed to permit the skilled operator to produce at a rate profitable to the shop.

Lastly, the industrial lathe must be available in quantities and at prices suitable for the industrial demands of the time. Even today few shops could make their own lathes, and all would find it more satisfactory to buy them from a machine tool builder.

Readers who have followed the details of the story of the lathe thus far will surely recognize that at least some of these requirements had been met in varying degrees

before Maudslay ever constructed his first lathe, sometime after 1797.

First, a lathe capable of machining workpieces of iron and steel of an industrial size had been used by Christopher Polhem as early as 1710, and we have lathes of similar capabilities in those of Vaucanson, Senot and David Wilkinson all prior to 1797. Second, the lathes of Polhem and Wilkinson were definitely driven by water power and provided means by which this power was utilized to turn the workpiece as well as to give power feed to a cutting tool carried in a slide rest. Both these lathes came into successful commercial use. We do not know the details of the spindle drive or the carriage feed of Polhem's lathe, but we have a clear picture of Wilkinson's. The actual means of power feed of Vaucanson's and Senot's lathes is certain, even if we could wish for more detail on their spindle drive mechanisms. Third, while we cannot be sure of the actual precision of the spindle bearings, guideways, and lead screws of the lathes of Vaucanson, Senot, and Wilkinson, all were constructed of materials and in dimensions and designs such that whatever precision may have been built into them would be very nearly reproduced in a workpiece turned on them. Precision construction of spindle bearings had been of concern to Chérubin as early as 1671, to Plumier in 1701, and to Geissler in 1795. The problem of precision guideways and accurate lead screws had been attacked with considerable success by the instrument makers of the third quarter of the 18th century. To be sure, their devices were not at all of industrial size, but at least the problem was recognized and some solutions were known by about 1795. Our fourth requirement, flexibility, requires change gears, found as early as Leonardo da Vinci and incorporated by Senot in 1795. Means of varying the spindle speed had been available since Chérubin in 1671. Senot and several predecessors had provided a sliding tailstock as well as a chuck. The face plate may go back to ancient lathes. Convenience in operation can be found, of course, in the many ornamental turning lathes, the fusee engines, and in the highly developed slide rest of the rose engine of 1771 as shown in Diderot. Vaucanson's lathe must have been rather inconvenient to operate, but Senot's and Wilkinson's would feel familiar to a modern machinist. Wilkinson's lathe was sufficiently useful to come into wide use in industry under profit making conditions. The Congressional Committee speaks specifically of it as saving "vast amounts of labor and expense." The approximate amount of saving can be estimated from the fact that, even though his patent had expired, the Congress voted him $10,000 "for benefits accruing to the public service for the use of the principle of the gauge and sliding lathe." Our last requirement, that the lathe be available in quantities and at prices suitable for the industrial demands of the time, was fully met by Wilkinson, for we have seen that his lathes came into wide use in the United States, and he even records that some were shipped to England.

We are, then, clearly left with the conclusion that all the elements of the industrial lathe were known and in use prior to Maudslay! Is he then to be relegated to a minor position in the history of tools? Most certainly not. We shall see that Maudslay, like Watt, Jacquard, Otto and a number of other great inventors, is the man who provided the great synthesis that embodied all these earlier elements in a design that set the fundamental form which the lathe was to have down to the present, the form which was to make the lathe a profoundly significant tool, a most important technical element of the industrial economy in which we live today.

We may then ask what Henry Maudslay[1] actually contributed to the development of the lathe. We have seen that the French and English instrument makers of the 18th century were concerned with precision in a number of their lathes, but these devices were for special purposes and were never used to produce what could properly be called parts of industrial machinery. From the very beginning of his career and throughout his life Maudslay had had a strong sense of the importance of precision in machine work. He insisted on it in everything that came out of his shop.[2] The application of precision to the design and construction of lathes capable of machining industrial workpieces is the first great technical contribution of Maudslay to the lathe.

In order to obtain this precision in an industrial lathe, once we make its parts of a material capable of accepting and retaining precision, we are concerned principally with three problems: 1) precision flat surfaces upon which to mount the head and tailstocks, and upon which the tailstock and carriage slide, 2) a precision lead screw, and 3) spindle bearings and tailstock centers to ensure precision rotation of the work.

Maudslay early recognized the importance of perfectly flat or true plane surfaces in machine tools. In his day the principal means of making them was the dexterous use of a file, in which Maudslay was himself perfectly skilled. But this hand skill required careful checking if precision was to be achieved. The usual method of checking then and now was by use of a standard plane surface, or surface plate. A small amount of red lead or other material is smeared lightly over the surface to be tested. It is then rubbed lightly with the surface plate, and any high points will be clearly indicated by the removal of the red lead.

This same method was also used by Maudslay to construct original surface plates.[3] In order to be sure that the surface plate is neither concave, nor convex, nor twisted, three plates are made at a time and checked against each other.[4] This technique was not original with Maudslay; what was new was his method of producing these surfaces by patient scraping, rather than grinding or filing off the high points until a perfect plane was achieved. In this work Maudslay exercised the greatest care and trouble to get exact surfaces. But what is more important, he had these standard planes put on the benches beside his workmen and insisted that they be used constantly to test their work, not only in making lathes, but in other machinery where precision plane surfaces were required.

Maudslay had used this method himself to achieve precision planes in the guideways of the first screw-cutting lathe of about 1797, as shown in Figure 41.[5] This lathe has a swing of about 3 inches and a length of about 3 feet. Its bed is formed by two triangular bars which

1. Most of the details of Maudslay's life and varied activities can be found in: Samuel Smiles, *Industrial Biography, Iron Workers and Tool Makers*, London, 1864, Chap. XII; Samuel Smiles, ed., *James Nasmyth, Engineer, An Autobiography*, London, 1883, Chap. VII; J. Foster Petree, ed., *Henry Maudslay, 1771-1831 and Maudslay, Sons and Field, Ltd.*, The Maudslay Society, 1945; J. Foster Petree, ed., *Henry Maudslay, 1771-1831 and Maudslay, Sons and Field, Ltd.*, The Maudslay Society, 1949. I am indebted to Major Rennie Maudslay for copies of these privately printed brochures as well as for generous help and hospitality kindly extended to me during my search for Maudslay papers in London. The account of Maudslay's work in Joseph W. Roe, *English and American Tool Builders*, New Haven, 1916, Chap. IV, is now outdated.

2. He built one of the first bench micrometers, his "Lord Chancellor." See the author's forthcoming *History of Shop Precision of Measurement and Interchangeable Parts.*

3. James Nasmyth, *Autobiography*, pp. 148-149.

4. It has since been shown that under certain conditions four plates are necessary.

5. Now in the Science Museum, London, M. 3117. 26,159 L.S. Exact copies are in the Smithsonian Institution, Washington, D. C. and in the Wilkie Museum, Des Plaines, Ill.

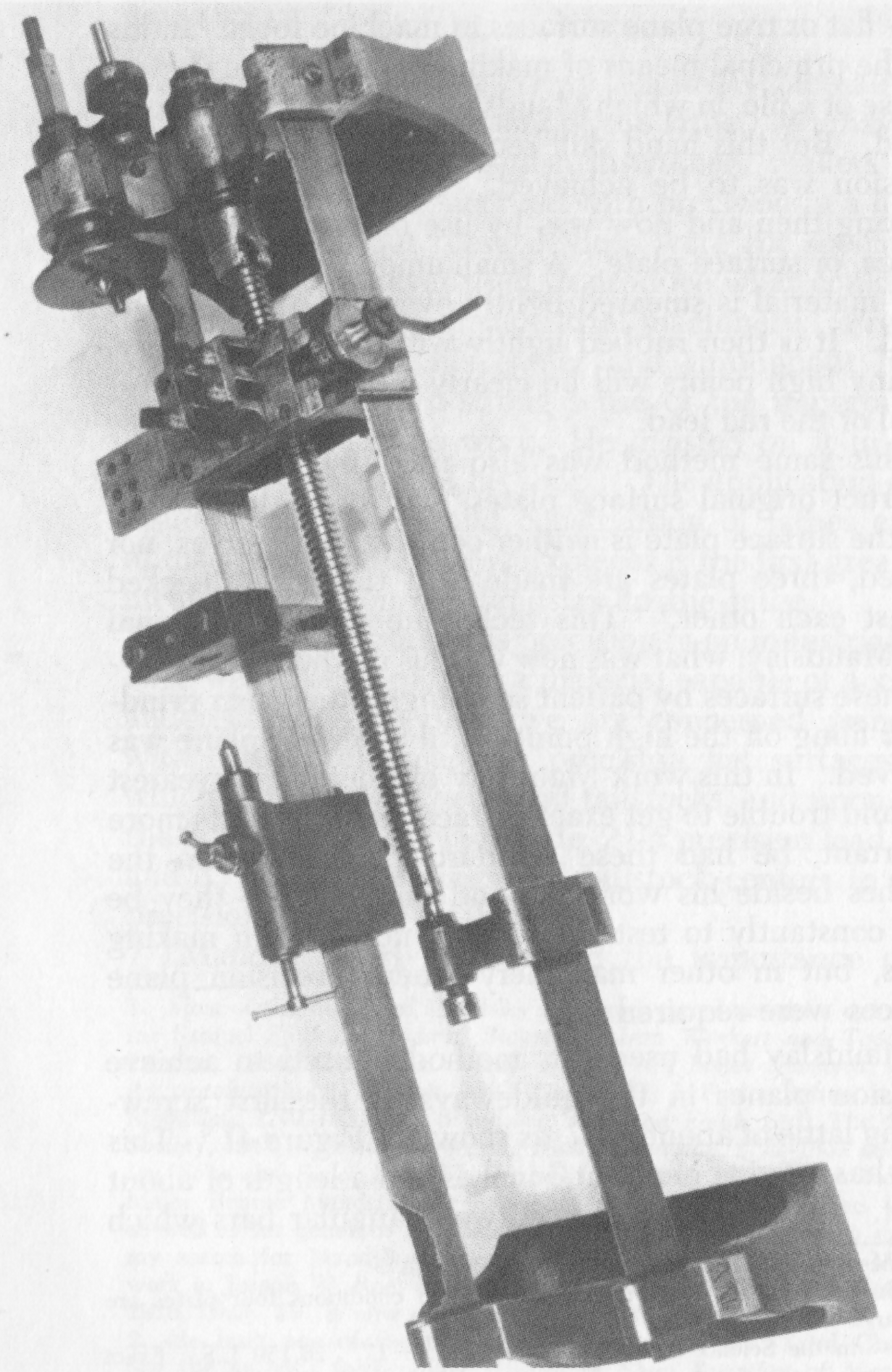


Fig. 41. Maudslay's First Screw-cutting Lathe, ca. 1797.
(British Crown Copyright, Science Museum, London)

also act as the guideways. Here Maudslay had used the prismatic form whose design advantages for guideways had already been known to Vaucanson. This is the first lathe of larger than instrument maker's size to have guideways made up of precision planes.

Little need be said of its gun metal slide rest, which was not new, but a distinct advance over the very poor design of 1794 attributed both to Maudslay and to Bramah, which had a slide rest made integral with the tailstock. The slide rest of 1797 had one important innovation in that its cross feed screw had a graduated dial to permit accurate determination of the depth of cut.

This lathe of 1797 does, however, have an accurate lead screw one inch in diameter and of 0.25 inch pitch, but with a rather narrow square thread. It is mounted between the guideways in a curious fashion. One end is supported in a bearing on the headstock, with provision made for use of change gears. The other end is supported on a center carried by a bracket mounted on one of the guide bars. The headstock end fits into a pin and socket drive, all of which strongly suggests that to get the screw pitches he might want to cut Maudslay here used, as he had in earlier lathes, more than one lead screw, even with change gears. There is a split nut and clamping device to connect the slide rest with the lead screw as desired.

We should also note the use of a gibbed slide for the slide rest, a face plate on the spindle, and a conveniently adjustable tailstock. Except for the curious mounting of the lead screw this lathe has most of the basic features of the modern industrial lathe.

Maudslay's screw-cutting lathe of about 1800 shown in Figure 42[6] is of only instrument maker size, but more nearly resembles the proportions of the later industrial lathe. The guideways are flat and mounted on a separate

6. Also in the Science Museum, London, M. 3116. 26,160 L.S.

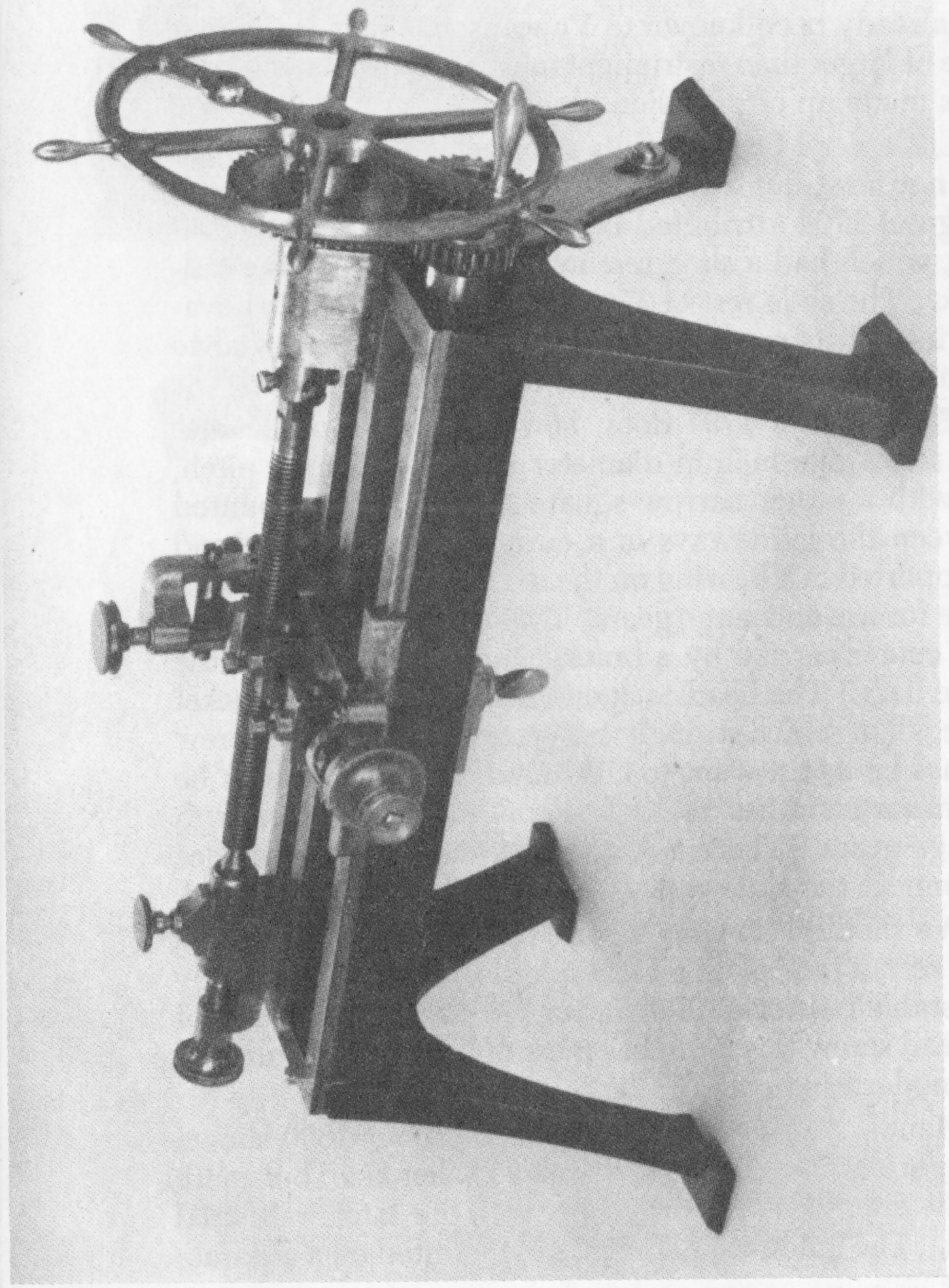


Fig. 42. Maudslay's Screw-cutting Lathe, ca. 1800. (*British Crown Copyright, Science Museum, London*)

cast iron bed of substantial design and supported on solid legs. The tailstock is partially carried on a separate guideway, and the slide rest carries a follower rest. The headstock spindle has a simple set-screw chuck. And the lead screw is now independently mounted in the frame at both ends. Except for the hand drive and its small size, we have here very many of the features of the early industrial lathe. Already we can see the beginning of Maudslay's synthesis of the essential elements of the industrial lathe.

The second element required for a precision screw-cutting lathe is, of course, a precision lead screw. On this element Maudslay also took the greatest pains.[7] He tried each of the various known methods of generating an original screw—the chain or band of steel, the inclined knife, the inclined plane, and various modifications of these and other methods. But he preferred the use of the inclined knife upon cylinders of wood, tin, brass, iron and other materials. His knife was designed to fit the cylinder closely and was mounted at the required angle on a block sliding on a bar of triangular cross section. The oblique incision carried the knife along the cylinder as it revolved. He made hundreds of screws in this way.[8] The best of these screws in soft material were used to generate screws in steel on a lathe very similar to that shown in Figure 41. In fact that lathe may be the actual one, for its curious method of mounting its lead screw would provide easy means for frequently changing to another lead screw. Holtzapffel tells us that Maudslay went later to stronger machines for this purpose. One had a triangular bar in the center for mounting the head and tailstocks, "whilst a large and wide side-

7. For details of this and later work on the precision lead screw see Charles Holtzapffel, *Turning and Mechanical Manipulation*, London, 1856, Vol. II, pp. 639-655.

8. His device for carrying out this process is in the Science Museum, London, M. 3119. 26,314 L. S.

plate, moving between chamfer bars attached to the framing, carried the sliding rest for the tool." This machine was driven by steam power. Holtzapffel rightly points out that this was the transition step from the lathe bed and guides of the lathes shown in Figures 41 and 42 to the modern screw-cutting lathe in which a strong lathe bed has one or more triangular ridges for guideways as well as flat ways to take the downward thrust.

In attempting to get the most precise and uniform lead screw possible Maudslay tried every "dodge" he could imagine. The original lead screws were turned end for end, the best portions were used successively, two guide screws were linked together in an ingenious mechanism which used their mean to traverse the screw-cutting tool. Minor errors were corrected by converting some of the steel screws into taps to cut dies which were used locally.

Maudslay finally had a splendid brass screw about seven feet long which was only one-sixteenth of an inch in error from its computed length. This was an error of about .002 inch per tooth. To correct this by using change gears, as Ramsden had done for his instrument screws, would have required one gear with 2000 teeth and another of 1999 teeth. Maudslay therefore invented a very clever linkage by means of which these very small corrections could be made with great ease.

Although careful microscopic examination of these screws showed them to be far more precise than was needed for machine shop work, Maudslay went on to produce screws of accuracy sufficient for purely scientfic purposes.

The last element required for a precision industrial lathe is adequate spindle bearings. In Figure 43 we see one of Maudslay's early lathes in which drive is through a step pulley on a spindle mounted between two bearings, one of which is already adjustable to provide a close fit of the tapered head bearing in order to ensure precision.

In 1830 he built[9] a face lathe of much larger size and having the front bearing executed as a split journal bearing of brass and a tapered rear bearing holding the spindle journals in tapered steel bushings. These bearings were very carefully constructed and are shown in Figure 44.

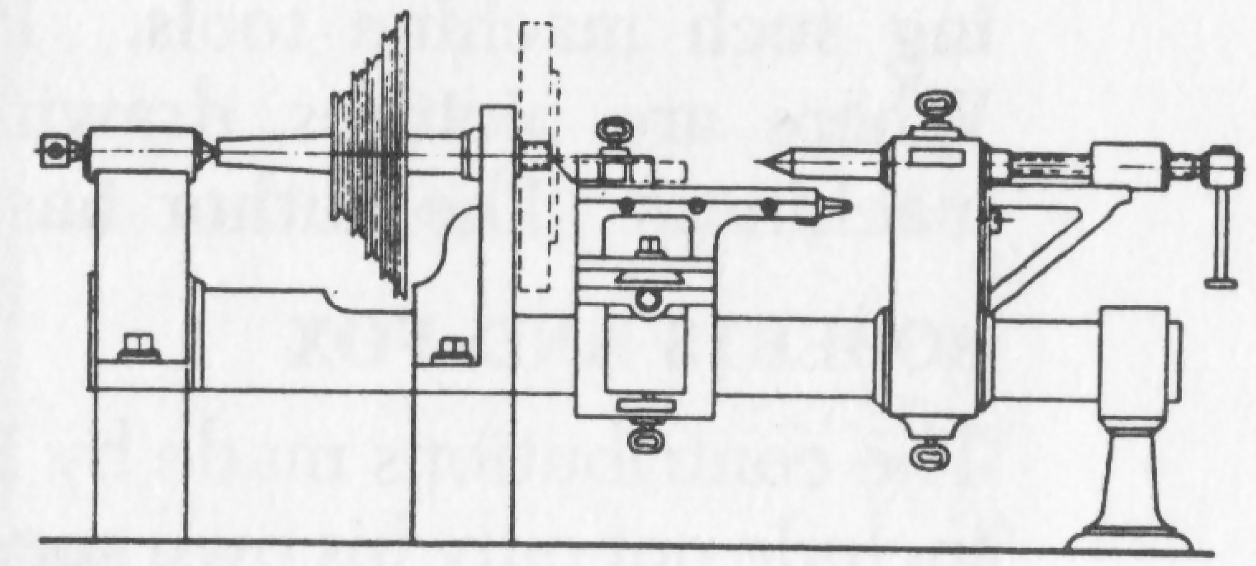


FIG. 43. MAUDSLAY'S SPINDLE DRIVE, CA. 1800. *(Wittmann)*

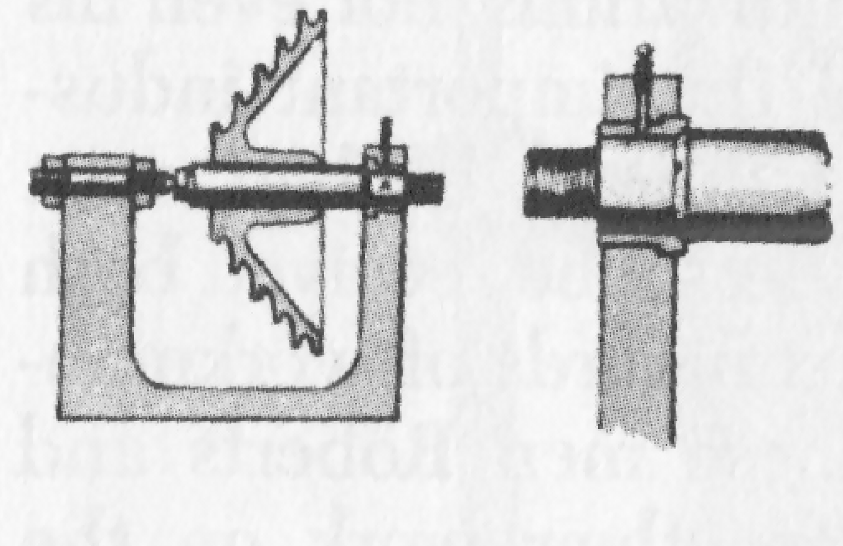


FIG. 44. MAUDSLAY'S IMPROVED SPINDLE BEARINGS, CA. 1800. *(Wittmann)*

This much larger lathe also had an interesting drive of the spindle, consisting of three gears on the spindle and a pinion on a countershaft. This countershaft could be shifted so as to engage the pinion with each of the three gears. This was therefore a fore-runner of the Norton gear box.

Clearly Henry Maudslay had put into one great synthesis all the elements of the lathe which had gone before. He had even anticipated some things that were to come. His precision lathes were built in sizes substantially greater than those of the instrument makers. But had he built a precision lathe of industrial size? Here we come to a peculiar gap in the sources. There can be little doubt that from 1810 to 1825 Maudslay, Sons and Field were supplying increasing numbers of lathes to British industry

9. W. A. S. Benson, "The Early Machine Tools of Henry Maudslay," in *Engineering*, Vol. 71 (1901), p. 65.

as well as using their product in their own shops. The marine engines and other machinery that we know they turned out must surely have been built on machine tools of industrial size. And we know Roberts, Clement and Fox to have produced industrial machine tools at this time. Nasmyth and others say that Maudslay was building such machine tools. But where is the evidence? Where are pictures, drawings or descriptions of these machines? The author has been unable to find them.

ROBERTS AND FOX

The contributions made by Henry Maudslay to the lathe include not only his own special innovations, nor even his great synthesis of the elements of this important industrial tool, they include also the influence he had on a number of other machine tool builders who received both their technical training and their standards of workmanship in Maudslay's shops. Of these men Roberts and Whitworth must be mentioned for their work on the lathe. We must also describe the lathes of another man who was not a pupil of Maudslay, but followed in the tradition he began—Fox.

To Richard Roberts[10] we owe several important innovations in the development of the industrial lathe: back gears, the bull gear on the spindle, and the form of automatic release of the carriage which became most common. The lathe shown in Figures 45a and 45b was built by Roberts in 1817.[11] It is of substantial industrial size, since it has a swing of 19 inches and a length of 6 feet. As can be seen in Figure 45a, it has a very strong and rigid bed, bolted to heavy cast iron legs. The lathe bed has three vertical members which are carefully braced by cross webs. The upper edges of two of these members form the guides for the head and tailstocks, the

10. For his life see Smiles, *Industrial Biography*, Chapt. XIV.
11. It is now in the Science Museum, London, M. 3689., S.M. 198-9, L. S.

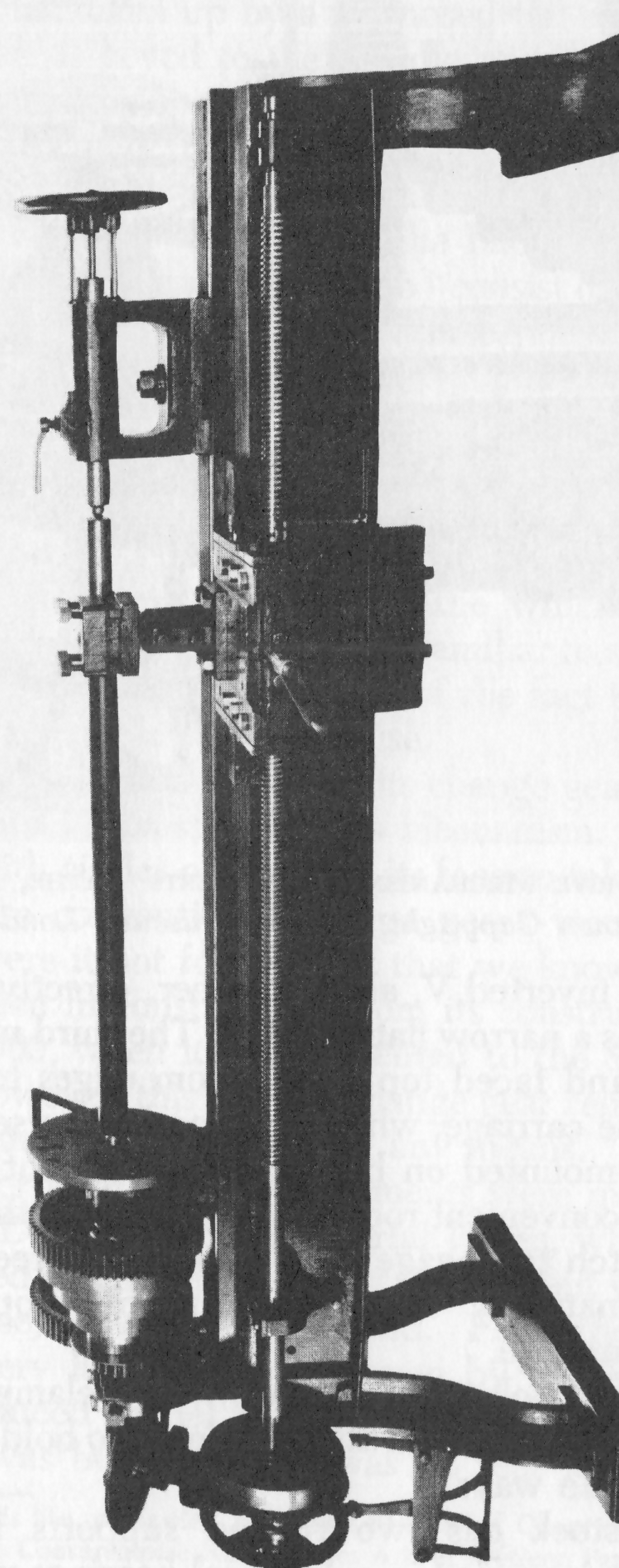


FIG. 45a. ROBERTS' INDUSTRIAL LATHE, 1817.
(British Crown Copyright, Science Museum, London)

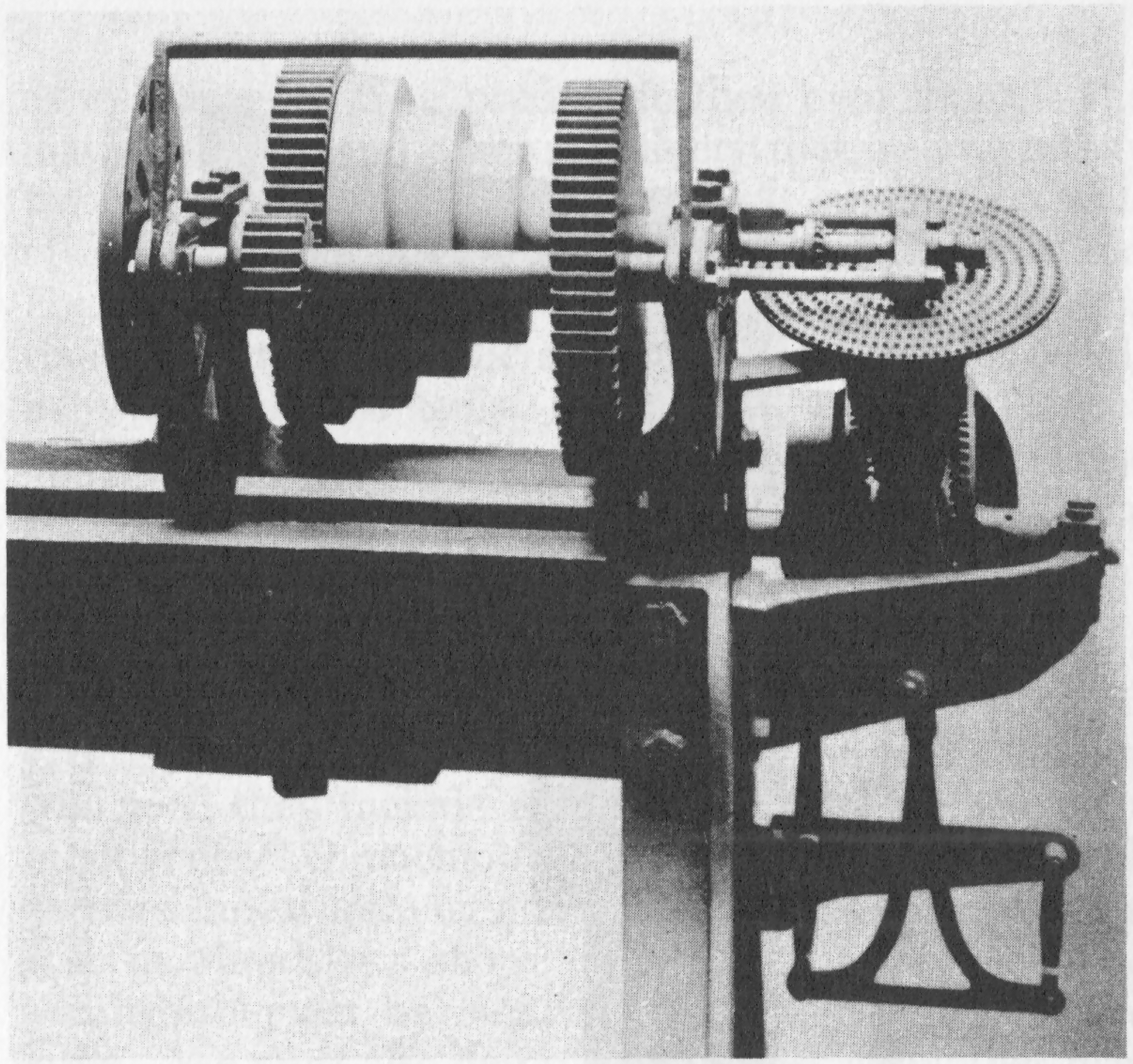


FIG. 45b. DRIVE MECHANISMS OF ROBERTS' LATHE, 1817.
(British Crown Copyright, Science Museum, London)

rear one is an inverted V, and the other, directly under the centers, has a narrow flat surface. The third member has bevelled and faced top and bottom edges to carry the front of the carriage, which has hand traverse. The lead screw is mounted on bearings on the front of the lathe bed. A convenient rod along the front of the lathe controls a clutch to engage or disengage the feed, and releases automatically when an adjustable stop on it contacts the carriage.

The tailstock looks very modern, with a clamp for its screw-operated spindle and another clamp to hold it from sliding along the ways.

The headstock has two rugged supports for the spindle, which is carried in cylindrical bearings with the

end thrust taken up by a flat-nosed tail screw. A heavy spur gear is keyed to the spindle near its front bearing, and a four step cone pulley with a spur pinion at its rear end turns freely on the spindle. The cone assembly can be locked to the large spur gear for direct operation, or can be released when using the back gears.

The back gears (Figure 45b) consist of a countershaft at the back of the headstock which carries a spur gear and pinion which can mesh with those on the cone pulley and on the spindle. A simple lever mechanism is provided to engage or disengage them. These back gears, of course, provide greater flexibility and permit very heavy work to be done on this lathe.

The features of Roberts' lathe which we have examined thus far would all seem familiar to a modern lathe operator and are all indicative of the fact that by 1817 a true *industrial* lathe was in use.

The feed drive gear with its change gears on Roberts' lathe forms a most ingenious mechanism. His use of a plate with circles of studs on its face to take the place of the more conventional change gears would provoke a smile were it not for the fact that we know this lathe to have been in constant use from its construction in 1817 until 1909, when it was presented to the Science Museum. However, this form of change gear remains a curiosity not adopted generally by any means.

Other important improvements were made by James Fox of Derby[12] in his industrial lathes, which were not only used extensively in Great Britain, but were exported to France, Germany and Poland. Fox lathes were sometimes very large machines, even by modern standards. The reduced model[13] shown in Figure 46 is of a lathe which was built in 1830, was 22 feet long, and had a

12. For his life see Smiles, *Industrial Biography*, Chapt. XIV.
13. In the Conservatoire National des Arts et Métiers, Paris, 4.084.–E.1849. An actual example, with original drawings, may be seen in the museum at Sielpia Wielka, Poland.

swing of 27 inches. The important features which were new with Fox were: 1) a rack for feed of the carriage when not cutting screws, a feature which helped to preserve the precision of the lead screw, 2) feed drive shaft with a sliding worm in the carriage, and provision for engaging and disengaging both the rack and the lead-screw drives, 3) separate guideways for the carriage and the tailstock; these guides were a combination of inverted V and flatways, 4) the I-form of the carriage, to give great stability and rigidity and thus add to precision.

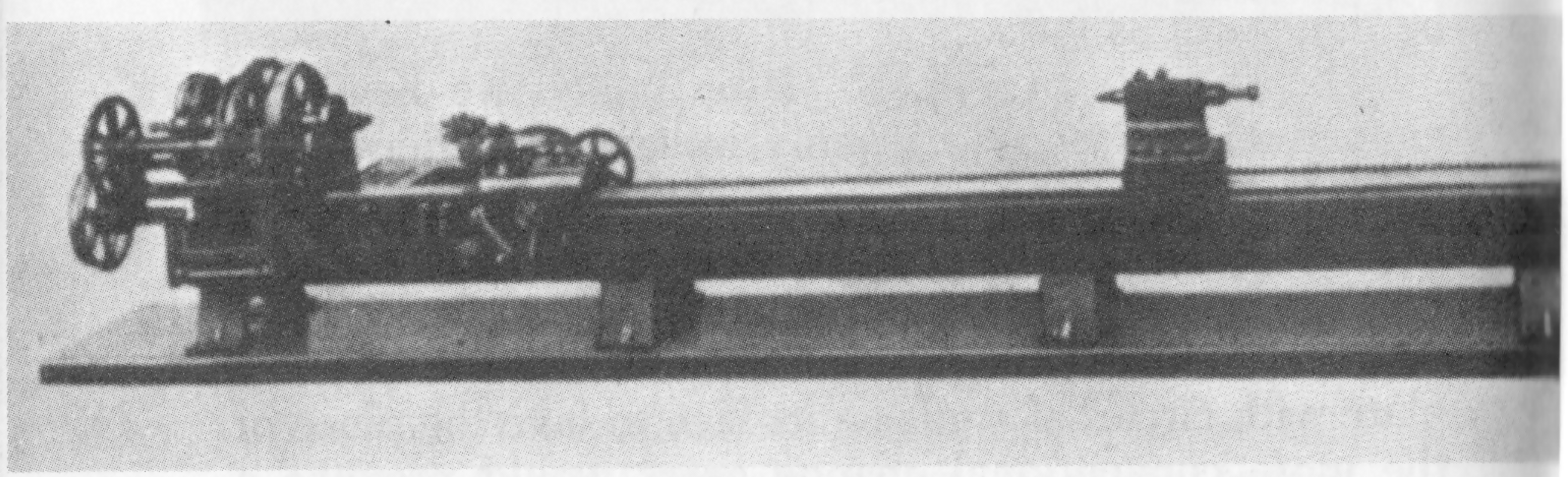


FIG. 46. HEAVY INDUSTRIAL LATHE BY FOX, 1830. *(Conservatoire National)*

Fox was also much concerned with improvement of the spindle bearings of the lathe. Two of his solutions are shown in Figure 47, where he is clearly trying to produce bearings to withstand the heavy thrusts of industrial turning, yet to maintain a high order of precision. This figure also shows some of the attempts made by Fox and others to improve the convenience and precision of the tailstock and its dead center.

With Roberts and Fox the essential features of the modern industrial lathe had been, by 1830, incorporated in lathes widely employed in industry, and the industrial lathe had come of age.

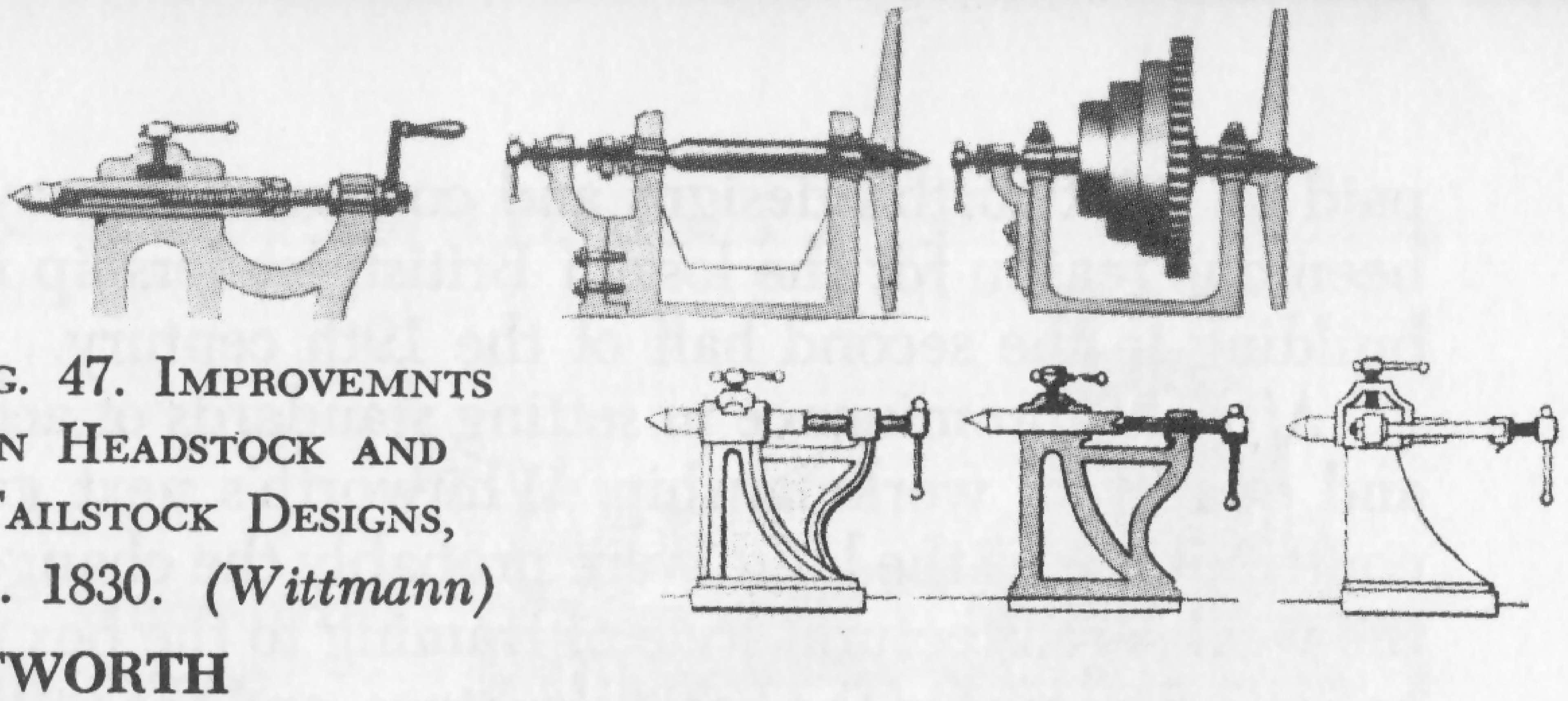


FIG. 47. IMPROVEMNTS IN HEADSTOCK AND TAILSTOCK DESIGNS, CA. 1830. *(Wittmann)*

WHITWORTH

The name of Joseph Whitworth is one to conjure with in the history of machine tools, for not only did he make specific technical contributions to the lathe, he was also the leading machine tool builder of the first half of the 19th century.[14] His important contributions to shop precision of measurement and to the standardization of screw threads will be dealt with in later monographs in this series. We are here only interested in his work on the lathe, for with him culminates the classical period of the English tool builders. He spans the whole period, for he went to work for Maudslay in 1825, worked for Holtzapffel and later for Clement. Then in 1833 he set up for himself in Manchester as a "Tool Maker from London." By Whitworth's time the classical machine tools had all been invented.[15] This does not, however, weaken Whitworth's importance, for he advanced the whole art of tool building by recognizing the fundamental conditions which had to be met for the lathe and other machine tools to satisfy industrial demands. In 1850 Whitworth was the most important manufacturer of machine tools in the world. He had introduced standards of accuracy unknown before in commercially produced industrial machine tools, and he had so improved their design and workmanship that Whitworth tools dominated English practice for over fifty years. In fact, the great respect

14. For his life see Smiles, *Industrial Biography*, Chapt. XIV.

15. The milling machine and the grinding machine were to come later, in the United States. See my *History of the Milling Machine*, 1960, and my *History of the Grinding Machine*, 1959.

paid to Whitworth's designs and construction may have been one reason for the loss of British leadership in tool building in the second half of the 19th century.

After his prominence in setting standards of accuracy and quality of workmanship. Whitworth's next greatest contributions to the lathe were probably the change from the weak, architectural style of framing to the box design or hollow frame for the basic structure, and the utilization of greater weights of metal to give the lathe stability and rigidity under the forces introduced in production industrial turning. These characteristics are to be seen in his lathe for machining heavy and very long workpieces. (Figure 48). This lathe is described in his Patent No. 8188 of 1839, and embodies a shiftable lathe bed. The shifting of the bed upon its foundation is done mechanically, and provision is made to maintain exact alignment as well as to supply power to the carriage. Later improvements in this lathe were described in his Patent No. 8705 of 1840.

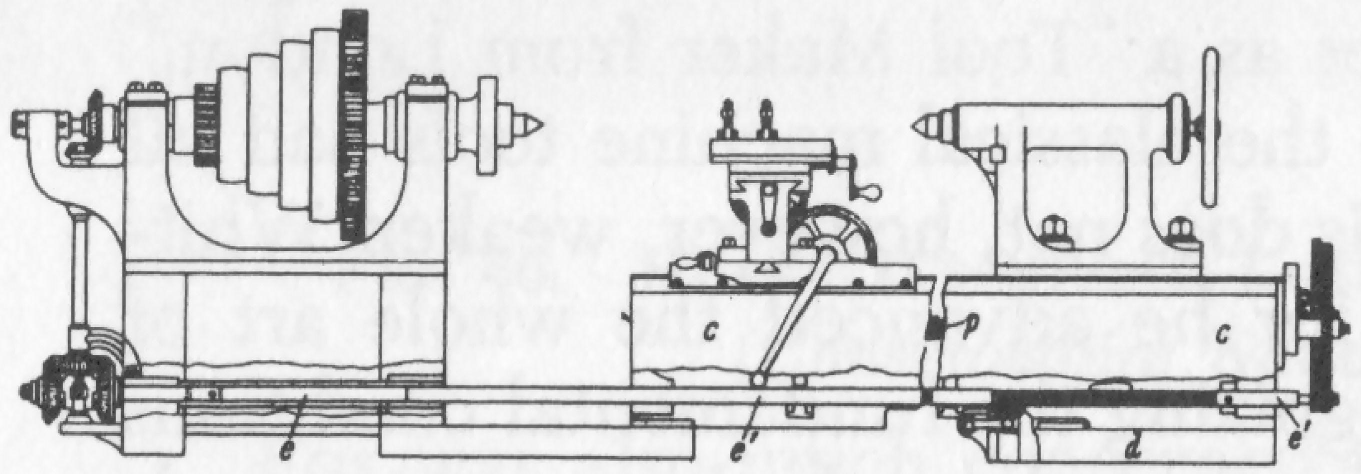


FIG. 48. WHITWORTH'S LATHE FOR LONG WORKPIECES, 1839. *(Wittmann)*

Whitworth was also concerned with shortening the time required for machining. The result, a multiple tooled lathe, is shown in his Patent No. 12,988 of 1849, where he has two or more tools arranged diametrically and cutting simultaneously by use of a second and opposing slide rest. Whitworth believed that this opposition would balance many of the forces producing vibration under heavy cutting loads. This machine never came into successful operation, probably through poor design and construction of its bearings, but it is evidence that

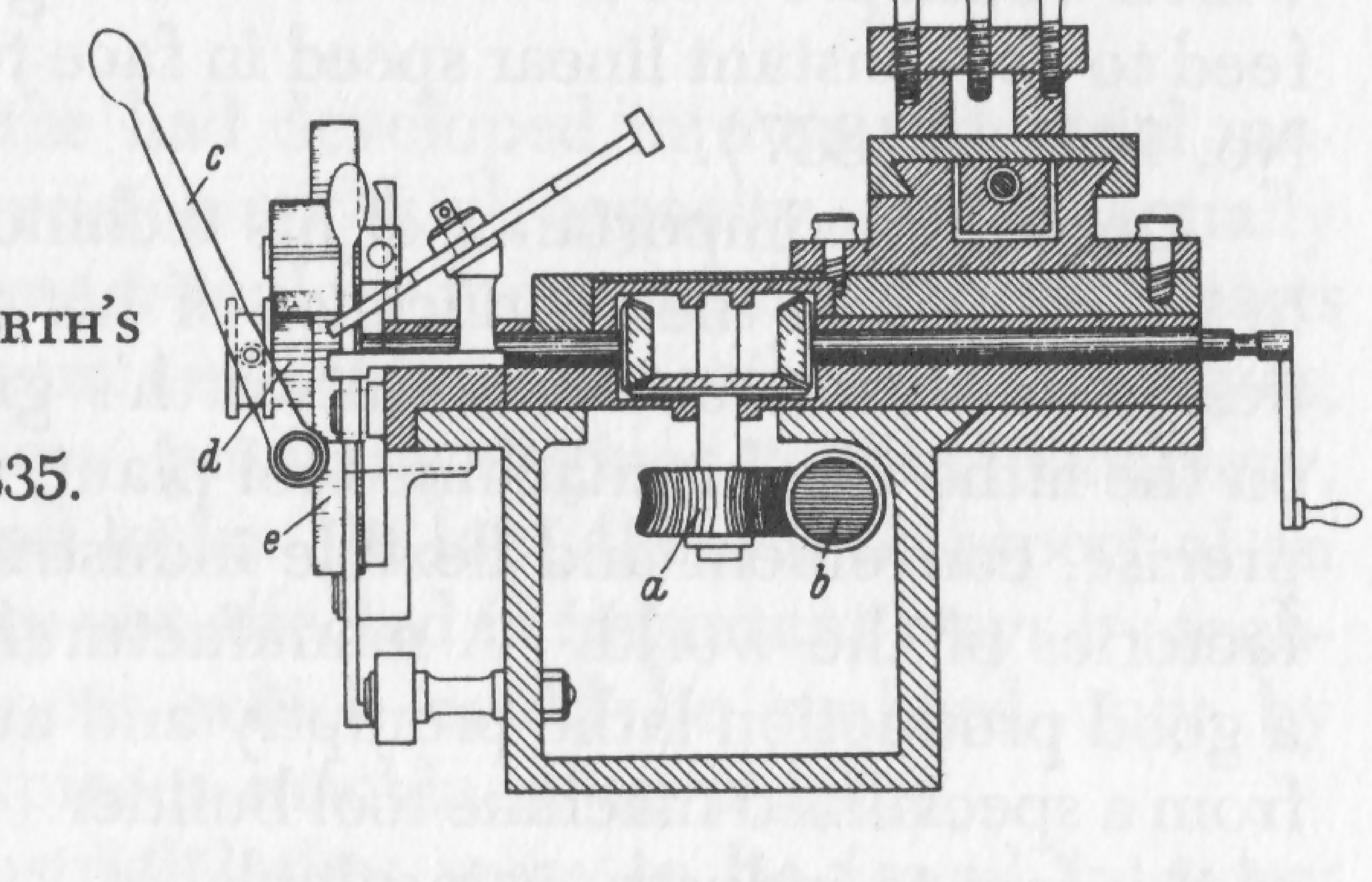


FIG. 49. WHITWORTH'S AUTOMATIC CROSS FEED, 1835. *(Wittmann)*

Whitworth foresaw this early the need for high production rates in machine tools.

Whitworth also saw into the future in his designs of specialized and automatic lathes. His patent No. 903 of 1855 describes a copying lathe for turning gun barrels, and his automatic lathe for turning conical parts with automatic feed of the tool is to be found in his Patent No. 1645 of 1857. Whitworth also included one of the basic elements of the later automatic screw machine by introducing the collet with an expanding cone in his Patent No. 6850 of 1835.

This same patent of 1835 also described two features of more significance for the general purpose lathe—the use of a half nut to engage the lead screw with the carriage, and automatic cross feed of the tool. As shown in Figure 49, the cross feed works by means of a worm-wheel and bevel gear drive. The worm-wheel "a" is continuously engaged with lead screw "b", but turns only when the carriage is stationary. At the back is a lever "c" which disconnects the cross feed when the pinion "d" is brought out of engagement with the gear "e". This device made possible power feed and smooth finish in face turning on the lathe. So concerned with this prob-

lem was Whitworth that he even attempted a mechanism which would provide a continuous change of rate of cross feed to get constant linear speed in face turning. (Patent No. 7441 of 1837).

Despite the importance of his technical contributions to the lathe and the significance of his standards for its design and construction, Whitworth's greatest influence on the lathe was his machine tool plant, which produced precise, convenient and flexible industrial lathes for the factories of the world. A manufacturer could then get a good production lathe promptly and at reasonable cost from a specialized machine tool builder. The importance of this fact to industry is incalculable.

CONCLUSION

By 1850 the lathe had developed into an industrial machine tool of precision and high capacity. It had equally become the primary tool for the construction of the parts required for steam and oil engines, railway locomotives, colliery machinery, pumping engines, textile machinery, draw bridges and locks. In fact, there is no aspect of an industrial society not affected in important ways by technological advances which could be realized only by means of workpieces machined on a lathe.

British industrial lathes were to be found in every industrial country in the world at work in its factories and its workshops. From the close of the 18th century until 1850 British machine tool builders had taken the lead in the invention, improved design, and manufacture not only of the lathe, but of all machine tools. In the light of the fact that British contributions to machine tools prior to 1800 had been extremely limited, we may ask why this sudden burst of interest, enthusiasm, and technical and manufacturing success in England? Writing in 1851 Professor Willis had observed: "In our own country the literature of this subject is so defective that it is very difficult to discover what progress we were making during the seventeenth and eighteenth centuries."[1] The fact was that prior to 1800 the great advances in all machine tools, and in the lathe in particular, had been made principally on the Continent, with a few in the United States. How then can we account for this new interest in machine tools in England?

The answer is, of course, the Industrial Revolution. This profound economic, social and political change had come about first in England as a result of a number of

1. Robert Willis, *Lectures on the Results of the Great Exhibition of 1851*, 1st. series, London, 1852, p. 306.

causes, not the least of which were technological innovations of the first magnitude—in power, transportation, mining and metallurgy, and in the manufacture of textiles. By 1750 these technological advances had already produced economic and social changes which demanded further technical improvements possible only when parts of machines could be produced cheaply and easily on machine tools capable of working large pieces of metal with precision. The story of Watt's ten year search for machines capable of creating in metal the designs for his steam engine is well known. Later the clumsy walking beam had to be retained for steam engines until the planer made possible a sliding cross head. There were similar problems in every type of machinery, to which only the industrial machine tool, and especially the lathe, could provide the answer.

The year 1850 also marks another turning point. Up to that year the great advances in machine tools had been English and the suppliers of industrial machine tools had been English. This English lead was after 1850 to be overtaken first by the Americans and later by the Germans, both in innovation and in manufacture. The lathe had been given its basic form by British mechanics; new forms such as the turret lathe and the automatic screw machine were to arise in other lands. And industrial countries were to go more and more to Germany and the United States for the production lathes they needed to outfit their factories to produce the flow of goods possible only in an industrial society.

Of course the development of the lathe by no means ended in 1850. In fact, the story of what happened to the lathe and other machine tools after 1850 is of greater interest and importance to the economic and social historian, for beginnings which it has been possible here only to suggest then flower into industrial changes of the first magnitude. For this technical development of

the lathe Wittmann describes in detail such important features as improvements in the spindle drive, the introduction of mechanical, hydraulic and electrical drive and control of the feed, improved rigidity of the lathe bed, and greater precision in the spindle bearings. He also goes into considerable detail on the efforts made toward reducing the work time by use of multiple tools, simultaneously or in succession, and by machining several workpieces simultaneously. But a more analytical study is required of these important contributions to high production rates for mass production. It is also necessary to tell the story of the growth of specialized and fully automatic lathes developed to meet the mass production needs of the sewing machine, the typewriter, the bicycle and the automobile. These two gaps in the technical history of the lathe I shall try to fill in a later monograph on the *History of the Turret Lathe and the Automatic Screw Machine.*

There it will be possible to trace the appearance of specialized lathes called into being by the needs of industry, the interaction of these specialized lathes on the general purpose lathe, the various types of lathes which resulted, as well as some technical features which resulted from the increasing production rates required by an industrial economy. It will also be possible to suggest some of the social results of more and more "building the skill into the machine" and wider use of automatic features. These technical innovations had profound effects, on the one hand, upon the working conditions and status of the machinist or "machine operator," as he is now more properly called, and on the other, on the growth of an increasingly skilled but much smaller group called "set-up men," who set up, adjust and repair these machine tools as they become more complex and more critical in industrial production.

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INDEX